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An Investigation of Bond in Reinforced-Concrete Beams

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AN INVESTIGATION OF BOND IN REINFORCED-CONCRETE BEAMS

BY

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This is to certify that the thesis prepared in the Department of Theoretical and Applied Mechanics by ROSCOE HARRISON ALBRIGHT entitled An Investigation of Bond in Reinforced Concrete Beams is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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TABLE OF CONTENTS

INVESTIGATION OF BOND IN REINFORCED CONCRETE BEAMS

INVESTIGATION OF BOND IN REINFORCED CONCRETE BEAMS

INTRODUCTION

Purpose of Tests: The purpose of these tests was to give additional information concerning the bond in reinforced concrete beams. Some attention has also been given to the diagonal stresses in the beams tested.

Scope of Investigation: The tests described in this thesis were a part of the work of the University of Illinois Engineering Experiment Station. This work is a continuation of the study of the bond between concrete and steel which was undertaken in 1909. The thesis of W. W. Manspeaker and A. W. Wand, presented June, 1912, described an earlier series of tests of a similar kind.

The beams were 8 in. wide and 12 or 14 in. in depth; 10 in. being the depth to the center of the steel. In general the reinforcement consisted of a single bar of large size; in a few of the tests four smaller bars were used. The reinforcing bars were straight throughout their length. Both plain and deformed bars were used.

A large percentage of reinforcement was used in order that bond failures or diagonal tension failures might be produced without overstressing the steel. The span was 6 ft. in all cases, and the load was applied at the third points. No web reinforcement was used as it was desired to study the relation of the diagonal tension resistance and bond in beams without web reinforcement.

Tests were also made to determine the effect of the repetition of the load which caused beginning of slip of the ends of the reinforcing bars.

Some of the beams were made with a 4 in. thickness of concrete

below the reinforcing bars, which is much greater than usual. The purpose of these tests was to study the effect on the bond strength of the greater resistance to web failures which these beams were expected to show.

Three beams were made by placing the reinforcing bar with its center 2 in. below the top of the beam. In the tests these beams were turned over and loaded in the usual way. It was the purpose of these tests to study the bond resistance of bars which are near the top of a beam when it is cast.

In a number of the tests, measurements were made of the amount of slip of the bar at different points of its length as the load was applied to the beam.

In order to compare the bond resistance in beams with that of bars imbedded in a mass of concrete, comparison pull-out tests were made on bars imbedded in 8 in. cylinders of concrete. 6 in. cubes and 8 x 16 in. cylinders were made from the same concrete for compression tests.

The test specimens include twenty-eight beams reinforced with $1\frac{1}{4}$ in., $\frac{3}{4}$ in. plain round bars, and $1\frac{1}{8}$ in. corrugated bars. Sixty-six pull-out specimens were made and tested for a comparison of their bond stresses to those developed in the beams. Thirty 6 in. cubes and fourteen 8 x 16 in. cylinders were made and tested to determine the compressive strength of the concrete.

TEST PIECES

Materials Used: Universal Portland cement was used in making the concrete. It was from the same shipment of cement used in the specimens of 1911-1912. Tests of the cement are given in Table I.

The sand was torpedo sand from Attica, Indiana. It was of good

quality, clean, and well graded. A mechanical analysis of five samples is given in Table II.

The stone was limestone from Kankakee, Illinois, which is representative of that used at the Engineering Experiment Station of the University of Illinois. The stone is from the same lot as that used in the specimens made in 1911-1912. A table from the thesis of W.W. Manspeaker and A. W. Wand, presented June, 1912, giving the mechanical test of the stone is given. (See Table III)

Concrete: The concrete was mixed in a 9 cu. ft. batch mixer, manufactured by the Marsh-Capron Campany, Chicago, Illinois. All materials were proportioned by loose volume but weights were recorded in order to secure a check on the amount of material in each batch. Men experienced in mixing and making test pieces were employed in the work. The mixing was continued for about 5 minutes after the last of the concrete material was placed in the mixer. The batch was then discharged on the concrete floor and later removed to the forms. Generally enough concrete was mixed in one batch to make two test beams and the corresponding auxiliary specimens. Medium steel was used and as it was not expected that the steel stresses would be high no tests on the reinforcing bars are reported in this thesis.

MAKING BEAMS AND MINOR TEST PIECES

Beams: All beams were 8 in. wide. The total depth was 12 in. except in those in which an additional thickness of concrete was placed below the steel. The length was 6 ft. 6 in. The depth to the center of the steel was 10 in. in all cases. The beam reinforcement consisted of one $1\frac{1}{4}$-in. plain round, one $1\frac{1}{8}$-in. corrugated round, or four $\frac{3}{4}$-in. plain round bars laid horizontally.

The beams were made in bottomless wooden forms, placed on a

sheet of heavy building paper. Concrete was placed around the bar and tamped. The form was then filled in layers of about 4 in. and tamped and spaded to insure a good compact concrete and to fill all the corners. Beams having 4 in. of concrete below the reinforcement and those having four $\frac{3}{4}$ in. bars were made in much the same manner, except that the reinforcing bars were supported in place by wires nailed to the top of the form. Three beams were made with the steel 2 in. below the upper surface. The forms were removed at the end of 7 days. Table IV gives a list of the beams made, with the reinforcement in each.

Three pull-out specimens were made from each batch by placing concrete, in an 8 in. cylinder 8 in. long, around a bar similar to that used in the corresponding beams. The bar projected about $\frac{1}{4}$ in. above and about 16 in. below the surface of the concrete as the specimen was made. The concrete was tamped into the form until it was full, thus the same conditions were obtained as in making the beams.

One 8 x 16 in. cylinder and three 6 in. cubes were made from each batch of concrete. Metal forms were used for all minor specimens.

Storage of Test Specimens: All forms were removed 7 days after the placing of the concrete. The beams were left on the laboratory floor in the position in which they were made for about 4 or 5 weeks. They were then piled in tiers of 3 or 4 beams until the time of testing.

The pull-out specimens were stored in open air. The beams and pull-out specimens were wet with water from a hose each day during the storage period. The cubes and cylinders were covered with damp sand.

FORMULAE

Computations of Stress in Beams: The unit bond stress was determined by means of the equation $u = \frac{V}{mod'}$, where

V = total end shear due to the applied load.

m = number of bars.

O = perimeter of one bar.

d' = arm of resisting moment of the beam.

d' varies with the amount of reinforcement. Assuming the ratio of the moduli of elasticity of steel to concrete to equal 15 the values for the depth of the neutral axis were taken from Fig. 8 of Bulletin No. 4 of the University of Illinois Engineering Experiment Station. From these values d' was computed by the formula $d' = d - \frac{1}{3}Kd$

where d' = arm of the resisting moment.

d = effective depth or depth of the center of the steel below the top of the beam.

K = ratio of the depth to the neutral axis to the effective depth of the beam.

The values used are given in Table VII.

The stress in the reinforcement was found by the formula $f_s = \frac{M}{Ad'}$, where,

M = bending moment.

f_s = unit stress in steel.

A = area of steel.

d' = arm or resisting moment.

The bending moment of a beam loaded at the $\frac{1}{3}$ points is equal to $\frac{1}{6}$ Wl

where W = applied load.

l = span length.

The vertical shearing unit stress in the beam was found by means of the equation

$$v = \frac{V}{bd'}$$

where V = total end shear.

v = unit shear.

b = width of beam.

d' = effective depth of the beam

The unit bond stress in the pull-out specimens is found by the formula

$$u = \frac{P}{oh}$$

where, u = average unit bond stress.

O = perimeter of the bar.

h = the length of embedment.

P = total load applied to bar.

METHODS OF TESTING

Beams: All the beams were tested in an Olsen testing machine having a capacity of 200000 pounds. In preparing the beams for the tests the sides were white washed so that cracks developing with the loading could be readily detected and traced. The ends of the reinforcing bars were exposed so that measurements could be obtained of the end slip of the steel. The beam was supported in the machine on rocker bearings, an iron plate being placed on the rockers and a cushion inserted between the beam and the plate to eliminate any irregularities in the surface of the concrete and thus get an even bearing. An I-beam transferred the load from the compression head to two rollers which rested on plates and cushions over the third points arranged in the same way as those on the rocker bearings. The end slip was measured with Ames extensometers. These instruments were graduated direct to indicate a movement of 0.001 in. but readings could be estimated to 0.0001 in. They were attached to the ends of the beam by means of metal yokes in such a manner that the plunger of the extensometer rested against the end of the reinforcing bar.

The beams in which the slip at the intermediate points was meas-

ured had extensometers along the bottom of the beam as well as at the end. These were fastened to a bracket which was attached to the beam with plaster of paris in such a way that the plunger of the instruments rested against steel plugs which had been screwed into threaded holes tapped in the bar before the beam was made. The bracket was notched so that the part which adhered to the beam was in the same cross plane as the plug thus the slip was taken over a zero gage length. The method of attaching the instrument is shown in Fig. 1. On several of the beams measurements of the bulging of concrete below the reinforcing bars were taken. The instruments were fastened in the same manner as those used to measure end slip, the plunger resting on the concrete directly under the bar. The deflection measurements were obtained by the use of a wood deflection bar 2 in. deep, $1\frac{1}{2}$ in. wide and 6 ft. 6 in. long. At the middle of this bar an Ames extensometer was attached, and at either end, 3 ft. from the center, iron points were fastened to keep the bar clear of the beam and to give fixed points for its support. This bar was clamped to the side of the beam. A small metal bracket was attached to the center of the depth of the beam with plaster of paris and rested against the plunger of the extensometer so that any deflection of the beam would be recorded on the dial. Before the test was begun the instruments were set at zero, the readings checked, and the machine balanced at zero so that only the applied load would be indicated during the test.

The machine head had a movement of .04 in. per min. Readings were taken of all instruments at increments of 2000 lb. load on the beams, and the cracks caused by these loadings were noted and mapped on the beam. Notes were made as to the manner of failure of each beam.

In the repeated load tests, the load which caused the first slip at the end of the bar was removed and reapplied alternately until the

beam failed. Readings were taken at zero loading, and then when the load was reapplied. These readings were taken at every loading for about 10 repetitions, then as the amount of slip per repetition lessened the loads were applied 5 to 20 times before readings were again taken. A summary of all beam tests is given in Table VIII.

Pull-out Tests: In making the pull-out tests a 100000 lb. Riehle testing machine having a movement of 0.05 in. per min. was used. The bearing face of the specimen was placed on a machined plate having a hole in its middle, through which the bar passed and was caught in the grip of the pulling head below. This plate rested on a hemispherical bearing block which rested on the weighing head of the machine. The hemispherical bearing permitted a direct pull to be exerted on the bar. The slip was measured by means of an Ames extensometer fastened to an adjustable clamp. The clamp fastened over the top of the specimen placing the instrument in such a position that the plunger rested on the projecting end of the bar. Readings of load on the bar were taken while the machine was running at slips of 0.0005 in., 0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.075, and 0.1 in. The classification and results of all pull-out specimens are given in Table IX.

Cube Tests: The cubes were tested in the same machine used to test the pull-out specimens. Plaster of paris was placed on the two surfaces that were to come in contact with the bearing plates in order to obtain a uniform bearing. To insure an equal pressure a hemispherical bearing block was placed on top of the cube, which came in contact with the movable head of the machine in testing. The maximum load only was observed in these tests. The results of the cube tests are given in Table X.

RESULTS OBTAINED AND DISCUSSION

Bond in Beams Reinforced with One $1\frac{1}{4}$ in. Plain Round Bar: The comparison of bond in the beams reinforced with $1\frac{1}{4}$ in. plain rounds and the corresponding pull-out specimens for the same amounts of slip will show the relation of these values. In the tests on beams reinforced with $1\frac{1}{4}$ in. plain round bars, the average computed bond stress for a slip of 0.0005 in. at the end of the bar, was 170 lb. per sq. in.; the average for the pull-out tests corresponding to the same beams was 254 lb. per sq. in. The lowest single test of the beams was 143 lb. per sq. in. and for the pull-outs 170 lb. per sq. in. In this group only two of the beams failed primarily by bond. As the greater part of the beams failed in diagonal tension the values given do not agree as closely as has usually been found in tests of this kind. The average bond at the slip of 0.002 in. in the beams was 196 lb. per sq. in. and in the pull-out specimens 329 lb. per sq. in. The bond in the pull-out tests ran about $\frac{1}{3}$ higher than that in the beams for the same amount of slip. The maximum bond stress was 211 lb. per sq. in. for beams and 412 lb. per sq.in. for pull-out specimens. In the beam tests the slip of the bars at maximum load was about 0.004 in., while in the pull-out tests the maximum load corresponded to a slip of about 0.02 in. This difference should be borne in mind in attempting to compare the beams and pull-out tests.

Beams reinforced with one $1\frac{1}{8}$ in. corrugated round bars: The end slip of the $1\frac{1}{8}$ in. corrugated bars was less than that of the $1\frac{1}{4}$ in. plain round bars before failure occurred. The average computed bond for a slip of 0.0005 in. in the beams was 261 lb. per sq. in. and for the pull-out specimens 259 lb. per sq. in. In this case there is but little difference between the bond in the pull-out specimens and in

the beams. The average maximum bond stress developed in the beams was 289 lb. per sq. in. and in the pull-out tests 520 lb. per sq. in. In nearly all the beams tested the concrete cracked along a horizontal plane beneath the bar thus relieving the bond for a considerable portion of the length of the bar near the ends. In the tests the slip of the bar at the end where failure occurred was about 0.0005 in. In the pull-out tests the maximum load came at a slip of about 0.05 in.

Beams Reinforced with Four $\frac{3}{4}$ in. Plain Round Bars: The beams reinforced with four $\frac{3}{4}$ in. plain round bars gave an average bond stress of 151 lb. per sq. in. at an end slip of 0.0005 in. and the pull-out specimens gave a value of 286 lb. per dq. in. For an end slip of .0005 in., the beams gave a bond stress of 151 lb. per sq. in. and the pull-out specimens gave a value of 286 lb. per sq. in. For maximum bond stress the beams gave 166 lb. per sq. in. and the pull-out specimens 421 lb. per sq. in. The end slip of the bar was about 0.0012 in. when failure occurred in the beams and about 0.02 in. when the greatest bond stress was developed in pull-out specimens. These beams failed by diagonal tension.

The Relation of Depth of Concrete below the Steel to Shear and Bond Stresses in the Beams: The presence of 4 in. of concrete instead of 2 in. below the center of the steel did not affect the bond stresses developed. In each set of three specimens there was one beam that gave a higher bond stress than those that had 2 in. of concrete below the steel, but on the average there was only a slight difference as is shown in Table X. The principal method of failure of the beams having the additional depth was by diagonal tension and horizontal shear along the steel. In making these beams it was necessary to

suspend the reinforcing bars on wires attached to nails driven in the top of the form in order to prevent settlement during the tamping. In the other specimens the bars were carried by a layer of concrete which had been placed previously. The bars supported in this way seemed to take nearly all the weight of the concrete above as that below settled in the process of setting. This had the effect of allowing the lower concrete to settle away from the lower portion of the bar, either partially or wholly, and to produce a plane of weakness in the beam at the level of the lower surface of the bar. This is the probable reason for the horizontal shear failures along the reinforcing bars.

Effect of Molding Beams Upside Down: Three tests were made with beams in which the reinforcement was placed with its center 10 in. above the bottom, instead of 10 in. below the top of the beam, in molding. These tests gave an average maximum bond stress of 131 lb. per sq.in. The first end slip started at about 90 lb. per sq. in. bond stress. In these beams all failures were in bond, while those in the other tests were mostly in diagonal tension. The average maximum bond in this case was 131 lb. per sq. in. and in those molded with the center of the steel 10 in. below the top of the beam the bond was 211 lb. per sq. in., or about $\frac{1}{3}$ greater. The shear varied in the same ratio, as shown in Table X.

Repeated Load Tests: Six beams were tested to determine the effect of releasing and reapplying the load causing the first end slip of the reinforcement. Three of these tests were on beams reinforced with one $1\frac{1}{8}$ in. corrugated bar, and three were reinforced with one $1\frac{1}{4}$ in. plain round bar. In the tests on beams reinforced with $1\frac{1}{8}$ in. corrugated bars, Beam No. 1066.4 was accidentally overloaded on the sixth repetition so gave no definite results. Beam No. 1066.5 was

loaded nine times to 10000 lb. with practically no change in the slip. The load was then increased to 14000 lb. This load which caused a slip of 0.0003 in. at the S end was repeated 250 times. During the repetition of the load of 14000 lb. corresponding to a computed bond stress of 238 lb. per sq. in., the slip increased very slowly from 0.0003 in. to 0.0012 in. at the N end of the bar and from 0 to 0.0015 in. at the S end. At intermediate points the slip was greater, but it was seen that at the rate at which the slip of the bar was increasing a very large number of repetitions would be required to produce failure. The load was then increased to 16000 lb. (272 lb. per sq. in. bond stress). This load was repeated 131 times. At the 125th application of the 16000 lb. load the slip at the N end had increased to 0.0062 in. and at the S end 0.0084 in. Upon releasing the load the ends of the bars showed a permanent movement of 0.0056 in. at the N end and 0.0087 in. at the S end. At this time owing to an accident to the testing machine the load was increased to 18000 lb. which caused failure of the beam. The slip of bar at different points during the repetition of the load is shown in Fig. . It seems probable that failure would have been produced under a load of 16000 lb. had the repetition of this load been continued. Due to the time required to test Beam No. 1066.5, Beam No. 1066.6 was loaded until a slip of 0.0007 in. had been measured at the end under a load of 14000 lb. This amount of slip was in excess of the amount which would bear repetition of load and the beam failed upon the second application. Of these three tests only one gave the kind of information desired. If Beam No. 1066.5 is an index of how the others would have acted, it would be safe to say that the beam reinforced with $1\frac{1}{8}$ in. corrugated bars would not fail by the reloading of the load which caused the first appreciable end slip unless loaded a very large

number of times.

The three beams reinforced with $1\frac{1}{4}$ in. plain round bars gave somewhat better results. Beam No. 1065.4 was loaded to 10000 lb. which gave a slip of 0.0003 in. at the N end and 0.0002 in. at the S end. This load was released and reapplied 179 times. Failure occured by bond at the N end upon the 179th loading. The slip increased uniformly up to about the 80th loading - here the slip began to increase more rapidly as is shown by the curves in Fig. . The curves in this figure also show that after 20 repetitions, the slip of the bar at the S end and all points along the bar S of the center of the beam was very slight, while all the points except No. 1, N of the center where measurements were taken, gave the same relative slip as the slip at the N end. The maximum slip at the 179th loading before failure occurred was 0.0195 in. at the N end and 0.0042 in. at the S end.

Beam No. 1065.5 was loaded till the first end slip, which occurred at 8000 lb. The load was repeated 5 times and as no further slip occurred the load was increased to 12000 lb. which gave an end slip of 0.0004 in. This load was repeated 120 times, when failure by diagonal tension occurred. In this beam the slip was quite uniform up to 70 repetitions, after this however the slip increased rapidly. In this beam as in Beam No. 1065.4 the slip of the bar in the S half of the beam was very slight while the slip in the N half was relatively the same as that at the N end.

Beam No. 1065.6 was loaded to 14000 lb. giving a slip of 0.0002 in. which caused an end slip of 0.0006 in. The beam failed by diagonal tension at the 40th repetition due to an overload. The slip up to the failure corresponds quite closely to that of the preceding two beams. This series of tests shows that a beam reinforced with one

$1\frac{1}{4}$ in. plain round bar would fail under the repeated application of the load which causes an end slip of 0.0002 to .0006 in.

Bulging of Concrete Below Reinforcing Bars: In most cases there was evidence of the bulging of the concrete at the time the bar began to slip at the ends. This is not likely the cause of failure however, since the beams having the 4 in. of concrete below the steel did not give much higher bond stress. The shear and bond stresses are dependent on the same elements, so they varied in the same proportion.

CONCLUSION

The beams tested show the corrugated bar to give the greatest bond stress. The average bond stress for the $1\frac{1}{8}$ in. corrugated round bars, was 289 lb. per sq. in., the $1\frac{1}{4}$ in. plain round bars gave 221 lb. per sq. in., and the $\frac{3}{4}$ in. plain rounds gave an average of 166 lb. per sq. in.

The addition of 4 in. of concrete below the steel in beams does not give enough extra bond resistance (if any) to warrant its use. The failures of the beams were by diagonal tension and horizontal shear and not in bond.

The effect of molding beams upside down tends to reduce the bond strength, due probably to the concrete settling away from the bar. The average value of the bond stress in the three tests made was 131 lb. per sq. in.

It is evident that in the corrugated bars the loading which causes the first end slip would have to be applied a very large number of times before failure would be produced. The number of repetitions would probably run up into the thousands. The repeated application of the load causing first slip in beams reinforced with round bars would probably cause failure at about 200 repetitions.

The bond stress in the beams was about $\frac{1}{3}$ less than that in the pull-out tests. The verification of this may be seen in Table X.

There is a measurable bulging of the concrete below the reinforcing bar in a beam at the beginning of end slip, but as the beams that had 4 in. of concrete below the bars did not give much higher bond stresses the theory that the bond fails by this bulging is somewhat discredited although it is believed that it does effect the bond stress to some extent.

TABLE I

BRIQUET TESTS OF UNIVERSAL PORTLAND CEMENT

Each value is the average of five tests

Series No.	Percent of Water	Penetration mm	Neat Cement 7 days	Neat Cement 28 days	1-3 Morter 7 days	1-3 Morter 28 days
1	22.2	10	592	712	211	285
2	23.5	9	584	765	201	302
		Average	588	738	206	294

Ottawa sand 20-30 was used in the making of the 1 to 3 mortar

By the Vicat test the initial set occurred at 3 hr. and the final test at 6 hr. 25 min.

These tests were made by Mr. B. L. Bowling of the Cement Testing Laboratory of the University of Illinois.

TABLE II

MECHANICAL ANALYSIS OF SAND

Average of five samples

Sieve No.	Percent Passing
3	100.0
5	90.9
10	69.1
12	63.8
16	58.3
18	48.4
30	31.1
40	19.5
50	6.5
74	2.9
150	0.9

TABLE III

MECHANICAL ANALYSIS OF STONE

Average of five samples

This table is reproduced from the thesis of

W. W. Manspeaker and A. W. Wand

Size of Square Opening	Separation Size Inches	Percent Passing
1 in.	—	100.0
$\frac{3}{4}$ in.	—	95.5
$\frac{1}{2}$ in.	—	66.7
$\frac{3}{8}$ in.	—	46.3
No. 3	0.28	25.9
No. 5	0.174	8.1
No. 10	0.091	3.4

TABLE IV

LIST OF TEST BEAMS

1 - 2 - 4 Concrete. Universal Cement. All beams 8 x 12 in. in section except as otherwise noted, 10 in. to center of steel, 6 ft. 6 in. long. No stirrups

Beam Numbers			Description of Reinforcement
1065.1	1065.2	1065.3	One $1\frac{1}{4}$in. plain round
1065.4	1065.5	1065.6	$1\frac{1}{4}$in. plain round
1065.7	1065.9	1065.9	$1\frac{1}{4}$in. plain round; 4 in. of concrete below steel
1066.1	1066.2	1066.3	$1\frac{1}{8}$in. corrugated round
1066.4	1066.5	1066.6	$1\frac{1}{8}$in. corrugated round
1066.7	1066.8	1066.9	$1\frac{1}{8}$in. corrugated round; 4 in. of concrete below steel
1065.8	1067.2	1067.3	4, $\frac{3}{4}$in. plain rounds
1067.4	1067.5	1067.6	4, $\frac{3}{4}$in. plain rounds; 4 in. of concrete below steel
1068.2			$1\frac{1}{4}$in. plain round
1069.1	1069.2	1069.3	$1\frac{1}{4}$in. plain round; beam made upside down

3 pull-out specimens, 1 flexure beam, 3 6in. cubes, and 1 8 x 16 in. cylinder, were made from each batch.

TABLE V

LOG SHEET FOR A TYPICAL BEAM TEST

March 4, 1913 Abrams
Albright

Beam No. 1066.1 One $1\frac{1}{8}$ in. corrugated Bar

Load lb.	Center Deflection in.	S	N	Slip of bar inches 1 9"N	3 15"N	5 21"N	7 27"N	9 33"N	2 9"S	4 15"S	6 21"S	8 27"S	10 33"S	Bulging over bar. in. A	B	Bond lb/sq. in.
0	0	0	0	0	No Instrument	0	0	0	0	0	0	0	0	0	0	0
2000	.005	0	0	0		0	0	0	0	0	0	0	0	0	0	34
4000	.014	0	0	.0003		.0001	0	0	.0006	.0002	0	0	0	0	0	68
6000	.027	0	0	.0009		.0003	0	0	.0013	.0012	.0002	.0005	0	0	0	102
8000	.041	0	0	.0016		.0008	.0002	0	.0026	.0019	.0004	.0009	0	0	0	136
10000	.054	0	0	.0029		.0019	0	0	.0040	.0022	.0008	.0016	.0002	.0001	0	170
12000	.071	0	.0002	.0040		.0040	L .0002	.0002	.0050	.0022	.0011	.0036	.0002	.0001	0	204
14000	.089	.0007	.0003	.0050		.0050	.0010	0	.0061	.0061	.0011	.0058	.0012	.0001	0	238
15000	---	.0010	.0003	----		----	----	----	----	----	.0012	.0170	.0190	----	-	225

Diagonal Tension Failure at South end.

TABLE VI

LOG SHEET FOR A TYPICAL PULL-OUT TEST

Abrams
Albright

No. 1065.9

$1\frac{1}{8}$ in. corrugated round bar

Slip in.	Load lb.	Bond Stress lb. per sq.in.
0	0	0
.0005	4300	137
.001	5800	184
.002	7400	235
.005	9100	290
.01	10300	328
.02	11000	350
.05	10900	347
.075	10600	338
.100	10400	332

TABLE VII

VALUES OF d' AND OTHER FUNCTIONS USED IN COMPUTING THE BOND STRESSES IN THE REINFORCED CONCRETE BEAMS

No. of Bars	Size of Bar	% of Reinforcement	K	d' in.	mod'	b d' sq.in.	Area of Steel sq.in.
1	$1\frac{1}{4}$ in. plain round	1.534	.465	8.45	33.2	67.6	1.2272
1	$1\frac{1}{8}$ in. corrugated round	1.2425	.500	8.33	29.4	66.6	0.994
4	$\frac{3}{4}$ in. plain round	1.657	.513	8.29	58.5	66.3	1.7652

TABLE 8

TESTS OF REINFORCED CONCRETE BEAMS

Loads are given in pounds and, stresses in pounds per square inch The Test Span was 6 feet -0 inches. The load was applied at the third points.

Beam No.	Age at Test Days	Size and Kind of Bar	At First Slip of Bar: Load	At First Slip of Bar: Unit Band Stress	Maximum: Load	Maximum: Stress in Steel	Vertical Unit Shear	Unit Bond Stress	Failure
1065.1	62	$1\frac{1}{4}$ plain r.	10000	150	15500	17900	115	234	In Bond
.2	69	do	8000	120	125000	14500	92	188	" Bond
.3	78	do	12000	181	15900	18400	117	240	Diagonal Tension
1065.4	67	do	10000	150					Bond
.5	74	do	8000	120	Repeated Tests				Diagonal Tension
.6	79	do	14000	211					" "
1065.7	62	do	12000	181	16600	19300	123	250	Hor. Shear & Bond
.9	74	do	12000	181	17050	19800	129	257	Bond & Hor. Shear
.9	70	do	6000	90	14600	16900	108	217	Dia. Ten. & Hor. "
1066.1	63	$1\frac{1}{8}$" cor. r.	12000	204	15000	21800	111	255	Diagonal Tension
.2	69	do	14000	238	19050	27600	142	324	" "
.3	78	do	10000	170	17000	24600	127	289	" "
1066.4	65	do	12000	204					Diagonal Tension
.5	71	do	10000	170	Repeated Tests				" "
.6	78	do	10000	170					" "
1066.7	61	do	10000	170	11500	15100	86	196	Dia. Ten. & Hor. Sh.
.8	63	do	2000	34	20400	29600	153	346	" " " " "
.9	70	do	14000	238	18000	26100	136	306	Diagonal Tension
1065.8	68	$4\frac{3}{4}$ plain r.	6000	51	20000	16500	151	171	Diagonal Tension
1067.2	78	do	14000	119	20000	16400	151	171	Dia.Ten.&Hor.Sh.
1067.3	68	do	10000	85	18350	15000	138	157	Diagonal Tension

TABLE 8 (Continued)

TESTS OF REINFORCED CONCRETE BEAMS

Loads are given in pounds, and stresses in pounds per square inch. The Test Span was 6 feet - 0 inches. The load was applied at the third points.

Beam No.	Age at Test Days	Size and Kind of Bar	At First Slip of Bar Load	At First Slip of Bar Unit Band Stress	Maximum Load	Maximum Stress in Steel	Maximum Vertical Unit Shear	Maximum Unit Bond Stress	Failure
1067.4	63	do	4000	34	13700	11200	103	117	Dia. Ten. & Hor. Shear
.5	78	do	12000	102	20300	16700	153	173	" " " " "
.6	68	do	12000	102	15000	12300	113	128	Diagonal Tension
1068.2	70	1$\frac{1}{4}$ plain r.	12000	181	15050	17500	113	226	Diagonal Tension
1069.1	78	do	6000	90	9500	10000	70	143	Bond
.2	71	do	8000	120	10600	12300	78	157	Bond
.3	78	do	6000	90	6200	720	46	93	Bond

TABLE IX

PULL-OUT TESTS

1 - 2 - 4 Concrete, Universal Portland Cement, Graded Sand, and Crushed Limestone

One bar imbeded 8 in. in cylinder 8 in. in diameter.

Reference Number	Age at Test Days	Bond in pounds per square in. at Slip of (inches) .0005	.001	.002	.005	.010	.020	.050	.075	.10	Max. Bond Stress
		$1\frac{1}{4}$ in. plain round bar									
1065.1	65	170	186	215	258	290	348	325	314	301	348
		194	213	236	273	288	287	275	264	255	291
		194	211	234	279	317	344	339	326	309	344
Av.		186	203	242	266	298	326	313	301	255	328
Ratio to Max.		.567	.620	.738	.810	.910	.995	.956	.890	.778	
		$1\frac{1}{4}$ in. plain round bar									
1065.2	71	254	307	348	401	440	437	406	278	—	440
		302	352	383	406	407	354	359	246	—	407
		220	328	353	392	413	390	--	—	—	413
Av.		259	329	361	400	420	397				420
Ratio to Max.		.615	.785	.860	.955	1.000	.945				
		$1\frac{1}{4}$ in. plain round bar									
1065.3	81	290	332	358	388	416	437	453	—	—	453
		379	392	415	455	481	493	448	415	—	493
		306			396	446	516	454	540	521	516
Av.		325			413	448	482	452			487
Ratio to Max.		.667			.850	.920	.990	.928			

TABLE IX Continued

Reference Number	Age at Test Days	Bond in pounds per square in. at Slip of (inches) .0005	.001	.002	.005	.010	.020	.050	.075	.10	Max. Bond Stress
		$1\frac{1}{4}$ in. plain round bar									
1065.4	72	273	325	348	389	396	400	370	--	—	400
		257	288	307	334	360	367	360	339	323	367
		211	311	358	390	410	400	384	366	--	410
Av.		247	308	338	371	389	389	371			392
Ratio to Max.		.630	.785	.858	.945	.992	.992	.945			
		$1\frac{1}{4}$ in. plain round bar									
1063.5	64	163	180	199	203	211	214	191	--	—	214
		99	114	115	155	265	370	373	—	318	373
		254	272	284	302	311	309	302	292	--	311
Av.		172	189	199	203	262	298	289			299
Ratio to Max.		.575	.632	.665	.678	.875	.996	.967			
		$1\frac{1}{4}$in. plain round bar									
1065.7	63	226	250	254	271	272	275	268	260	250	275
		228	241	254	278	287	279	252	237	225	287
		159	180	199	234	243	251	234	227	216	251
Av.		204	224	236	261	267	268	251	241	230	271
Ratio to Max.		.753	.827	.870	.962	.985	.990	.927	.890	.850	
		$1\frac{1}{4}$ in. plain round bar									
1065.9	85	199	216	230	262	287	294	279	264	253	294
		179	211	238	301	312	322	312	302	289	322
		137	184	235	290	328	350	347	338	332	350
Av.		172	204	234	284	309	322	313	301	291	322
Ratio to Max.		.534	.634	.726	.881	.960	1.000	.971	.935	.904	

TABLE IX Continued

Reference Number	Age at Test Days	.0005	.001	.002	.005	.010	.020	.050	.075	.10	Max. Bond Stress
		Bond in pounds per square in. at Slip of (inches)									
		$1\frac{1}{8}$ in. corrugated round bar									
1066.1	63	263	309	331	362	396	445	524	—	—	524
		228	257	278	315	352	384	426	—	—	426
		257	270	291	324	349	367	373	—	—	387
Av.		249	279	300	334	399	399	441			446
Ratio to Max.		.557	.625	.672	.748	.895	.895	.989			
		$1\frac{1}{8}$ in. corrugated round bar									
1066.2	63	287	336	366	404	461	518	435	358	—	518
		223	299	322	345	376	406	443	522	488	522
		306	348	365	377	412	457	492	522	—	522
Av.		272	328	352	375	416	460	457	367		521
Ratio to Max.		.522	.628	.688	.718	.798	.881	.877	.703		
		$1\frac{1}{8}$ in. corrugated round bar									
1066.3	87	237	296	334	414	475	528	575	—	354	575
		258	304	356	427	480	510	562	595	530	595
		272	342	385	456	510	560	607	610	—	610
Av.		256	314	365	432	488	533	581			593
Ratio to Max.		.432	.530	.615	.727	.824	.898	.980			
		$1\frac{1}{8}$ in. corrugated round bar									
1066.4	72	231	272	290	323	353	388	461	500	495	510
		240	258	275	334	373	412	452	413	—	452
		244	296	337	373	387	393	417	389	—	445
Av.		238	275	301	343	371	398	443	434		469
Ratio to Max.		.507	.586	.641	.732	.791	.848	.946	.925		

TABLE IX Continued

Reference Number	Age at Test Days	.0005	.001	.002	.005	.010	.020	.050	.075	.10	Max. Bond Stress
		Bond in pounds per square in. at Slip of (inches)									
				$1\frac{1}{8}$ in. corrugated round bar							
1066.7	63	287	280	305	340	367	370	334	284	—	370
		225	256	266	293	320	328	361	396	335	396
		184	247	264	280	286	305	300	325	327	327
Av.		232	261	278	304	324	334	332	335		364
Ratio to Max.		.637	.716	.762	.835	.890	.916	.912	.920		
				$1\frac{1}{8}$ in. corrugated round bar							
1066.8	64	214	239	251	260	266	276	310	341	309	341
		277	288	290	285	306	325	339	324	—	339
		231	265	279	293	311	324	362	418	—	436
Av.		241	264	273	279	294	308	370	361		372
Ratio to Max.		.648	.683	.734	.750	.790	.829	.995	.970		
				$1\frac{1}{8}$ in. corrugated round bar							
1066.9	73	293	364	403	460	495	505	424	325	—	505
		300	378	444	522	565	600	635	643	565	643
		212	258	357	437	484	516	555	—	—	555
Av.		268	333	401	473	515	540	538			568
Ratio to Max.		.472	.586	.705	.832	.906	.950	.947			
				$\frac{3}{4}$ in. plain round bar							
1065.8	63	318	354	385	414	435	440	420	405	380	440
		276	313	336	364	387	394	382	369	—	394
		251	271	282	319	334	348	318	287	—	348
Av.		282	313	334	369	385	394	373	354		394
Ratio to Max.		.715	.793	.846	.936	.977	1.000	.946	.923		

TABLE IX Continued

Reference Number	Age at Test Days	Bond in pounds per square in. at Slip of (inches) .0005	.001	.002	.005	.010	.020	.050	.075	.10	Max. Bond Stress
		$\frac{3}{4}$ in. plain round bar									
1067.2	81	320	337	417	470	504	484	418	—	—	504
		349	406	438	476	493	500	455	418	—	500
		379	392	415	455	481	493	448	415	—	493
Av.		349	392	423	467	493	492	440			499
Ratio to Max.		.700	.781	.848	.935	.990	.987	.882			
		$\frac{3}{4}$ in. plain round bar									
1067.3	73	250	260	271	303	324	330	330	319	314	330
		202	303	330	368	378	394	368	340	319	394
		—	298	319	332	333	372	356	346	340	372
Av.			287	307	334	345	365	351	335	324	369
Ratio to Max.			.778	.833	.905	.935	.989	.951	.908	.878	
		$\frac{3}{4}$ in. plain round bar									
1067.4	64	232	240	—	—	288	284	266	—	—	288
		266	—	278	296	302	286	258	—	—	302
		249	—	263	272	268	264	236	—	—	272
Av.		249				286	278	253			287
Ratio to Max.		.868				.996	.970	.882			
		$\frac{3}{4}$ in. plain round bar									
1067.6	73	—	—	260	266	293	303	303	303	298	319
		266	282	303	340	373	383	367	346	324	383
		—	—	—	—	229	271	287	282	277	287
Av.						298	319	319	310	299	326
Ratio to Max.						.915	.978	.978	.950	.918	

TABLE IX Continued

Reference Number	Age at Test Days	Bond in pounds per square in. at Slip of (inches) .0005	.001	.002	.005	.010	.020	.050	.075	.10	Max. Bond Stress
		$1\frac{3}{4}$ in. plain round bar									
1068.2	63	172	205	222	253	264	266	256	241	—	266
		194	245	272	310	326	326	301	—	—	326
		249	262	285	319	336	343	332	314	302	343
Av.		205	237	293	294	309	312	296			312
Ratio to Max.		.657	.759	.940	.942	.990	1.000	.947			
		$1\frac{1}{4}$ in. plain round bar									
1069.2	73	148	167	184	215	231	247	252	249	239	252
		169	188	207	236	265	274	287	280	267	296
		186	217	231	249	262	269	274	264	253	274
Av.		168	191	207	233	253	263	271	268	253	274
Ratio to Max.		.614	.696	.755	.850	.924	.958	.989	.977	.924	

TABLE X

SUMMARY OF TESTS

Stresses are given in pounds per square inch

Reference Number	Beams Age	Beams Bond	Beams Shear	Pull-out Av. of 3 Tests Age	Pull-out Av. of 3 Tests Bond	Cubes Av. of 3 Tests Age	Cubes Av. of 3 Tests Compressive Strength
1065.1	62	234	115	65	328	67	1840
1065.2	69	118	92	71	420	90	2082
1065.3	78	240	117	81	487	75	2101
Av.	70	221	108	72	412	75	2007
1065.4	67	150	74	72	392	66	2220
1065.5	74	181	88	64	299	67	2055
1065.6	79	226	111	63	271	75	2101
Av.	73	186	91	66	321	69	2125
1065.7	62	250	123	63	271	79	2660
1065.9	74	257	129	85	322		
1065.9	70	217	108	73	274		
Av.	69	241	120	74	289		
1066.1	63	255	111	63	446	67	1840
1066.2	69	324	142	63	521	67	2845
1066.3	78	289	127	87	593	—	—
Av.	70	289	127	71	520	67	2342
1066.4	65	289	128	72	469	66	2220
1066.5	71	306	135	63	521	67	2845
1066.6	78	238	115	87	593	—	—
Av.	71	278	126	74	528	66	2532

TABLE X Continued

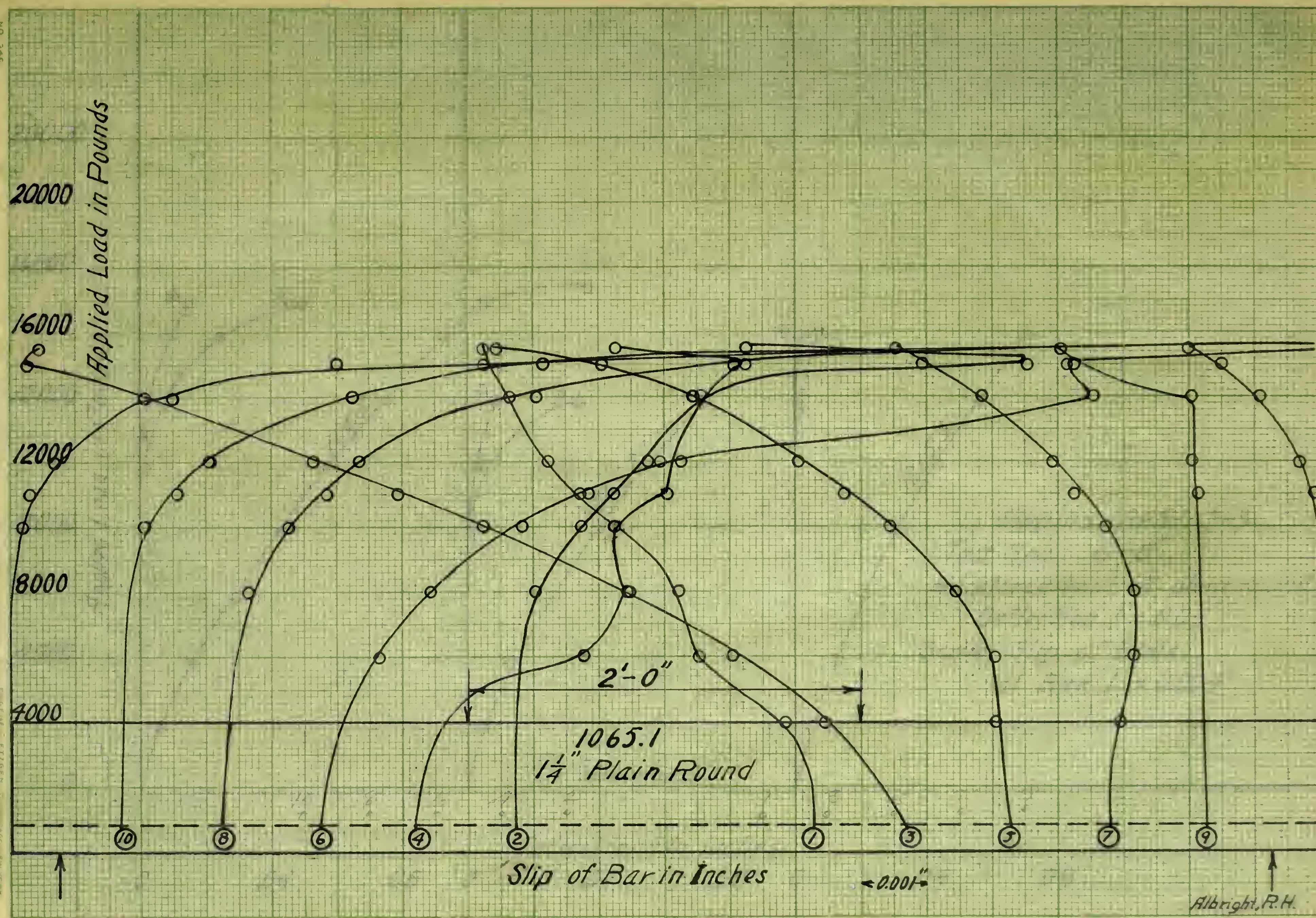
Reference Number	Beams Age	Beams Bond	Beams Shear	Pull-out Av. of 3 Tests Age	Pull-out Av. of 3 Tests Bond	Cubes Av. of 3 Tests Age	Cubes Av. of 3 Tests Compressive Strength
1066.7	61	196	86	63	364	79	2660
1066.8	63	346	153	64	372	67	2055
1066.9	70	306	136	73	568	—	—
Av.	65	283	125	67	435	73	2357
1065.8	68	171	151	63	394	74	2618
1067.2	78	171	151	81	499	69	2028
1067.3	68	157	138	73	369	—	—
Av.	71	166	150	72	421	71	2323
1067.4	63	117	103	64	287	64	1928
1067.5	78	173	153	81	499	69	2028
1067.6	68	128	113	73	326	—	—
Av.	70	139	123	73	371	66	1968
1068.2	70	226	113	63	312	—	—
1069.1	78	143	70	71	420	90	2082
1069.2	71	157	78	73	274	—	—
1069.3	74	93	46	85	322	—	—
Av.	74	131	65	76	339		

Note:

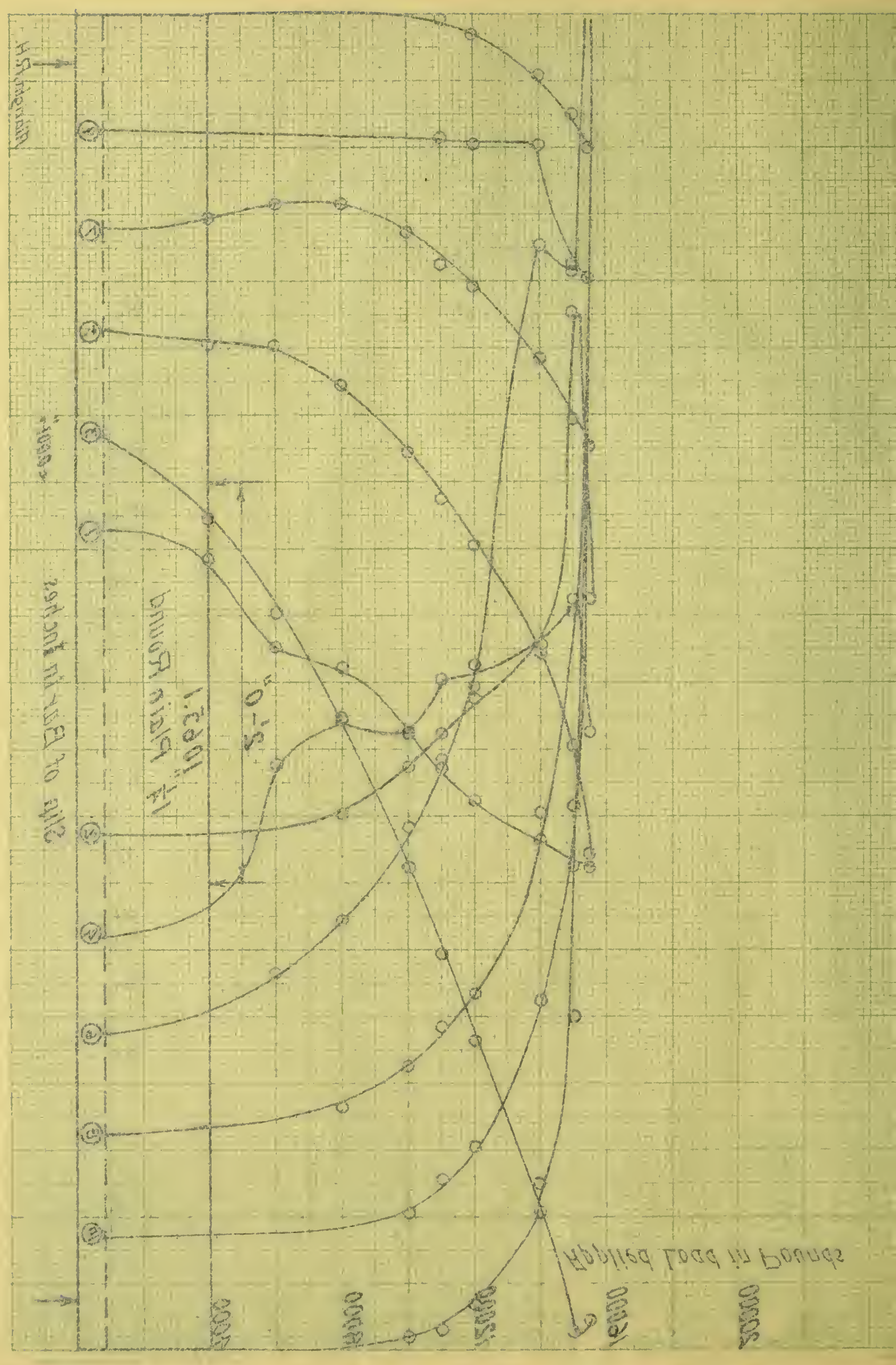
No cylinders or control beams were tested.

Only part of the cubes were tested.

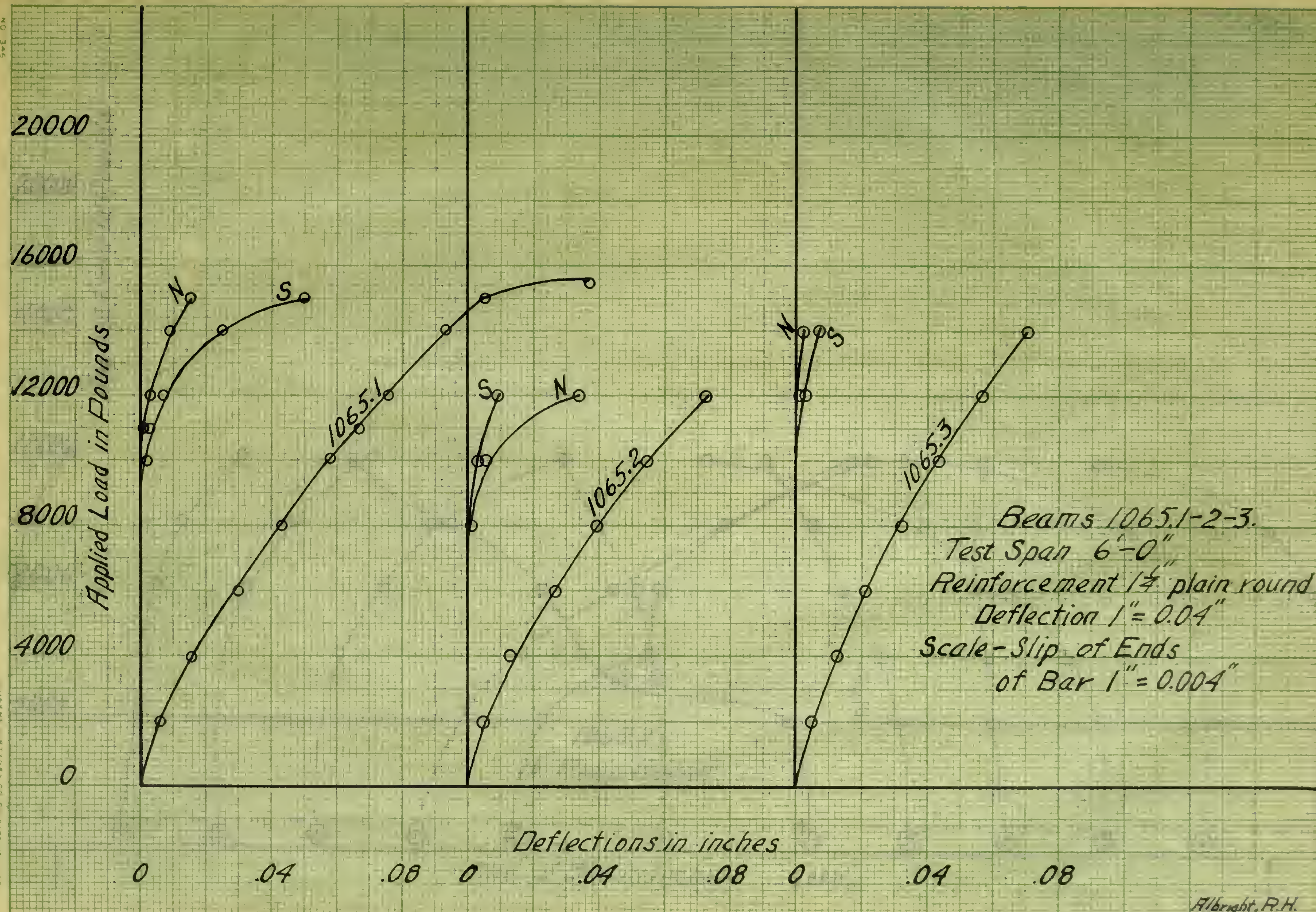
Values of one minor test piece corresponding to the same batch as two beams were used for each beam.

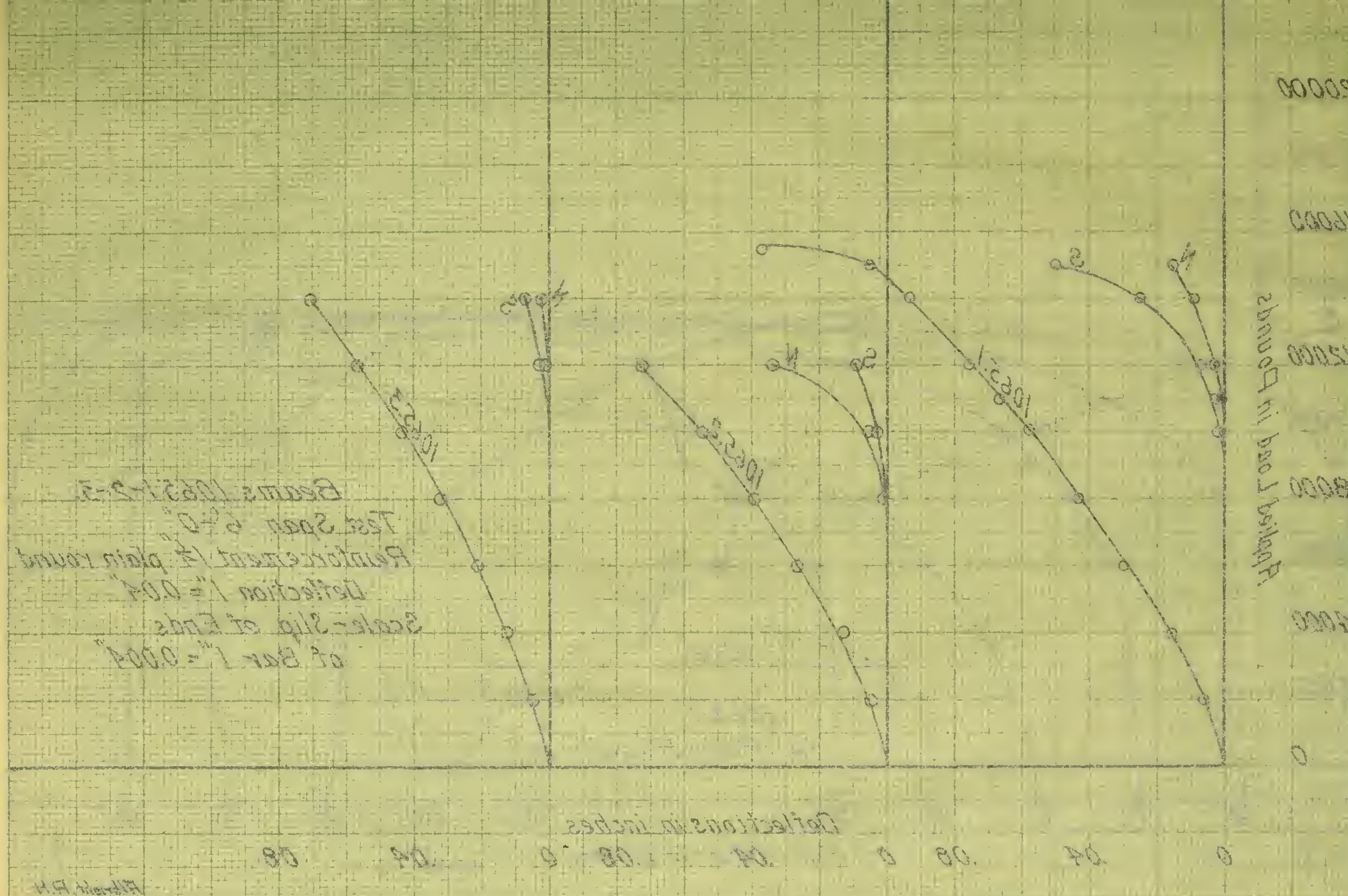


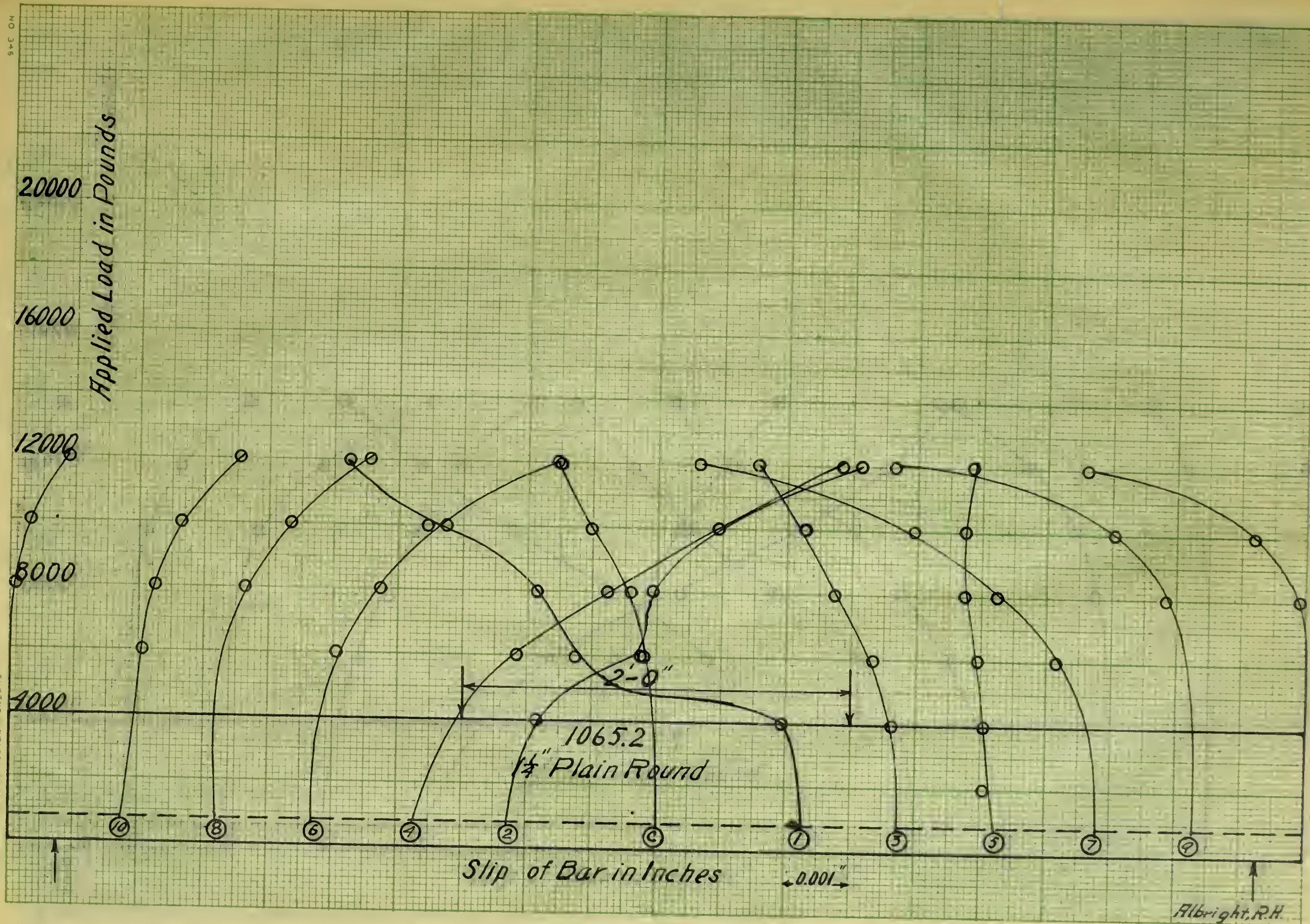
Applied Load in Pounds
20000
16000
12000
8000
4000
2'-0"
1065.1
1¼" Plain Round
10
8
6
4
2
1
3
5
7
9
Slip of Bar in Inches
0.001"
Albright, R.H.



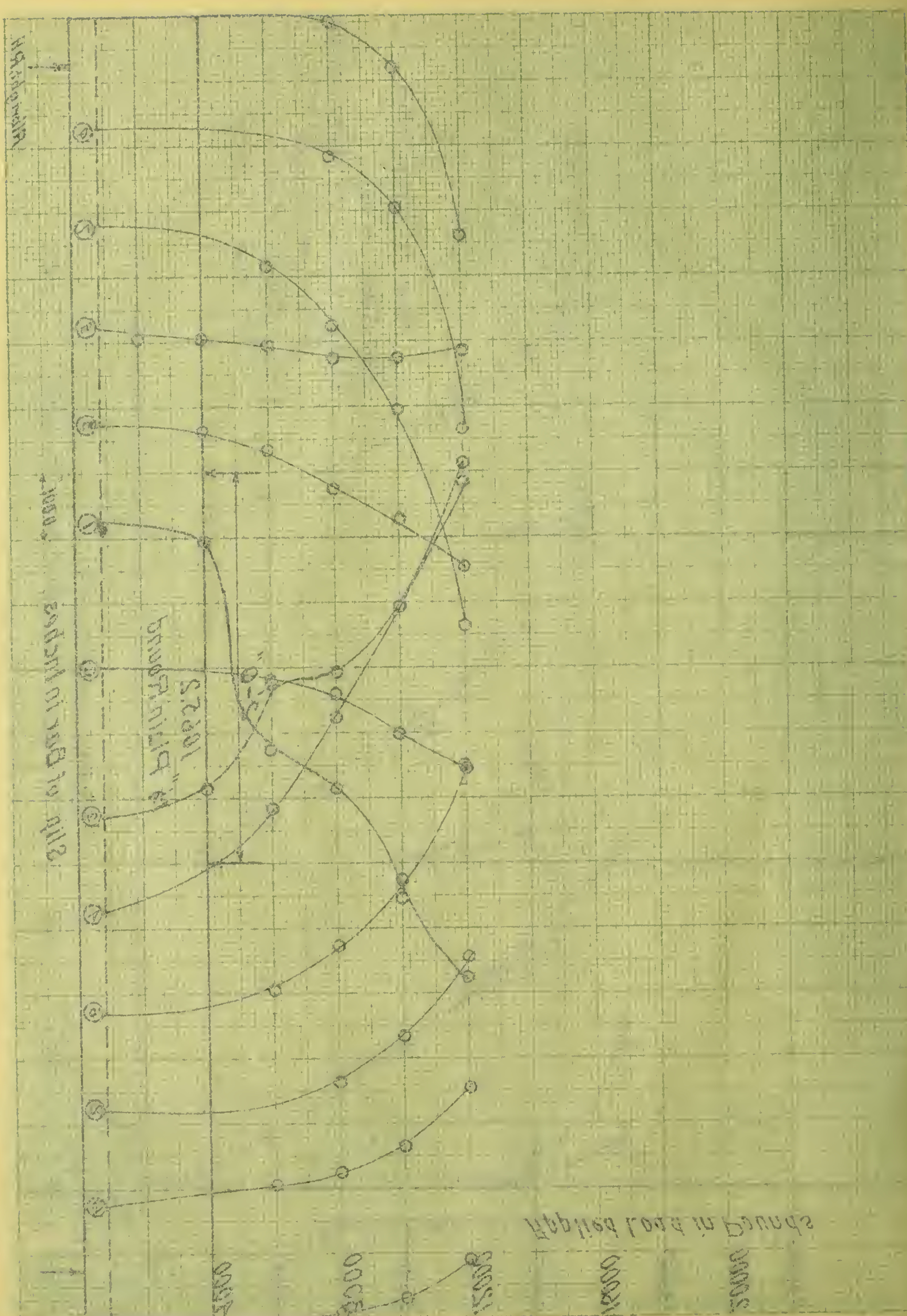
Slip of Bar in Inches
1/4" Plain Round
1065.1
2'-0"
Applied Load in Pounds
4000
8000
12000
16000
20000


Applied Load in Pounds
20000
16000
12000
8000
4000
0
N
S
1065.1
1065.2
1065.3
Deflections in inches
0
.04
.08
Beams 1065.1-2-3.
Test Span 6'-0"
Reinforcement 1¼" plain round
Deflection 1" = 0.04"
Scale-Slip of Ends
of Bar 1" = 0.004"
Albright. R.H.

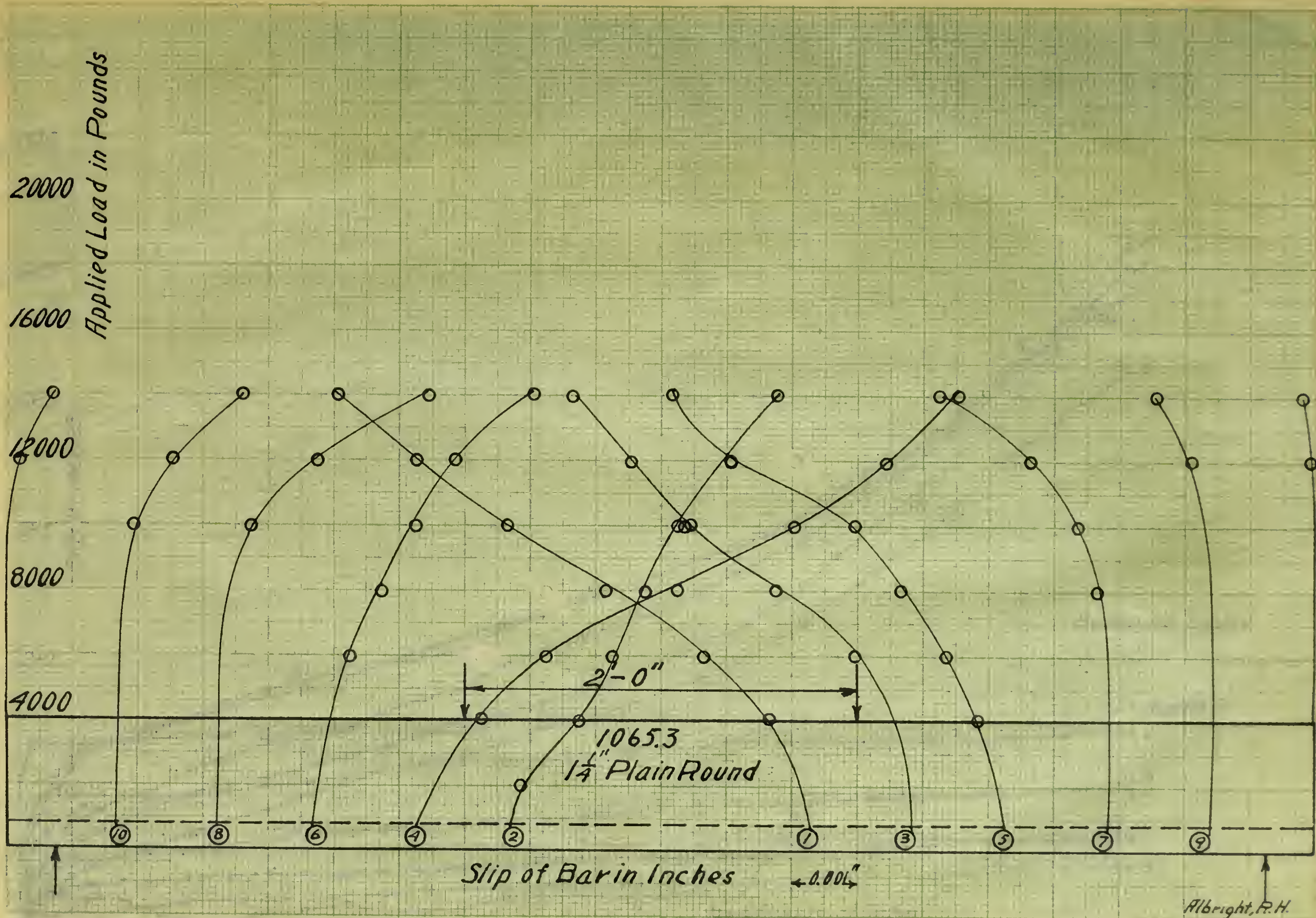

Beams 10631-2-3.
Test Span 6'-0"
Reinforcement 1/4" plain round
Applied Load in Pounds
Deflections in inches
10631
10632
10633
N
S



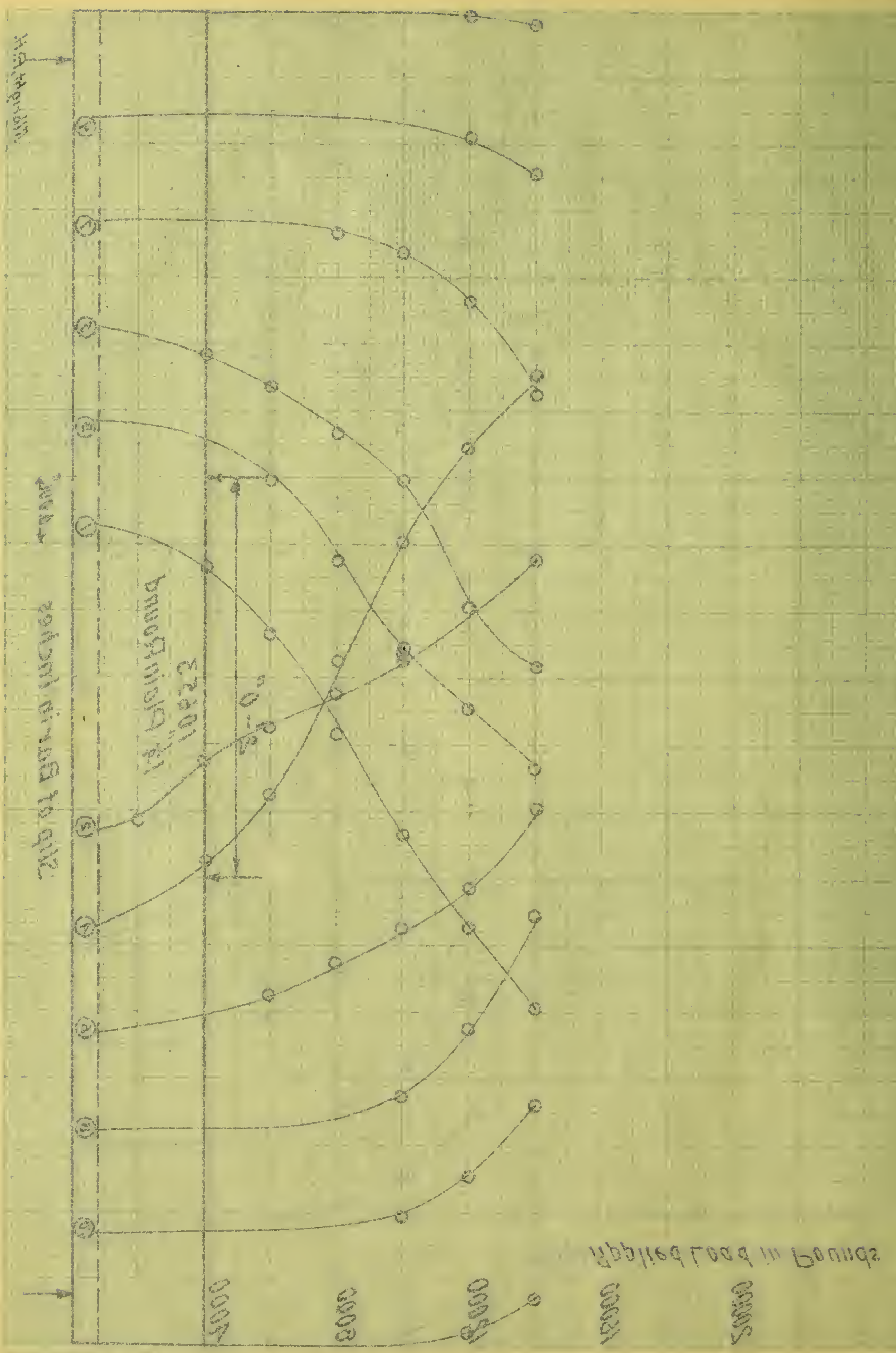
Applied Load in Pounds
20000
16000
12000
8000
4000
10
8
6
4
2
C
1
3
5
7
9
2'-0"
1065.2
1¼" Plain Round
Slip of Bar in Inches
0.001"
Albright, R.H.



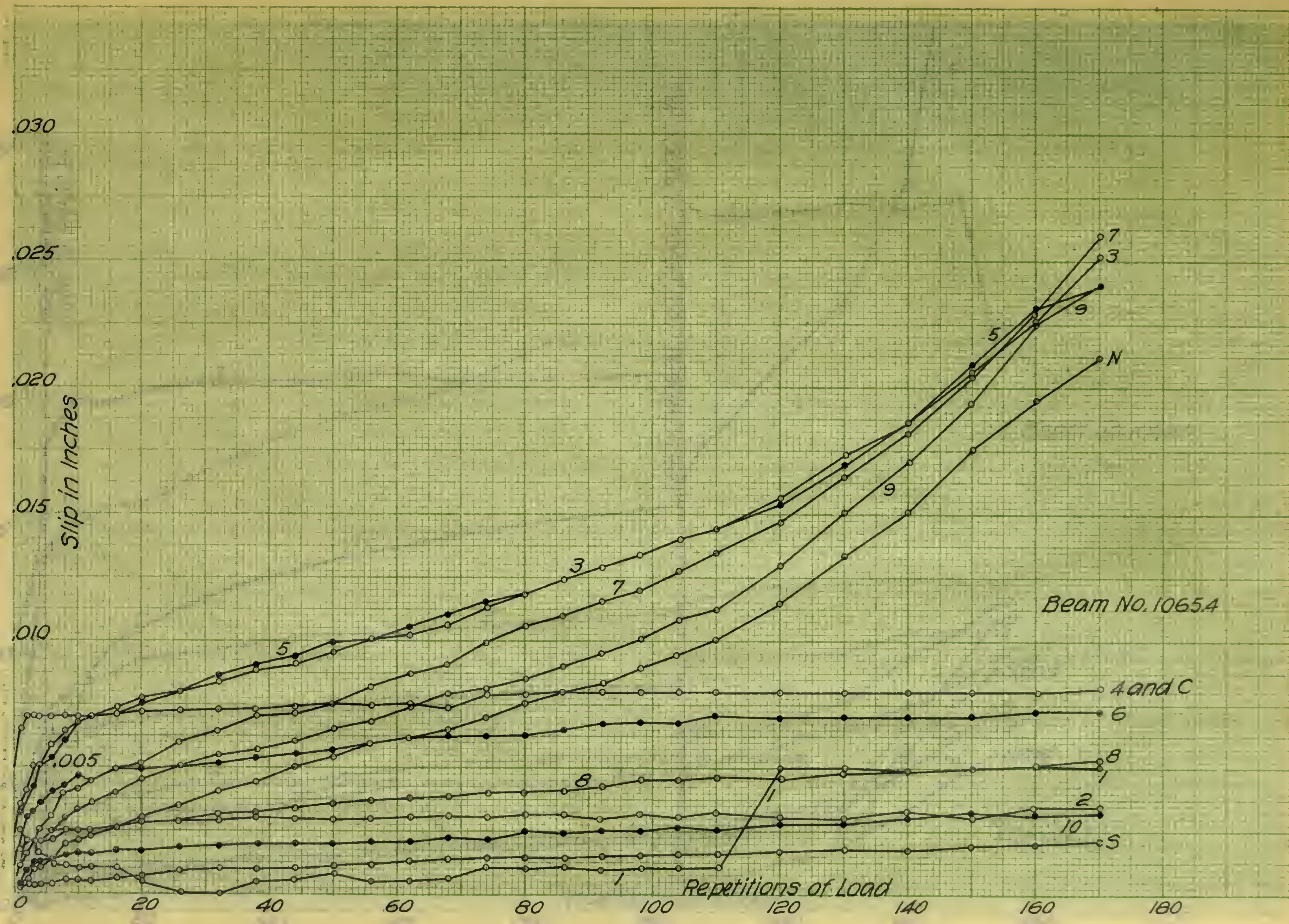
Slip of Bar in Inches
Applied Load in Pounds
1665.2
Plain Round
4000
8000
12000
16000
20000



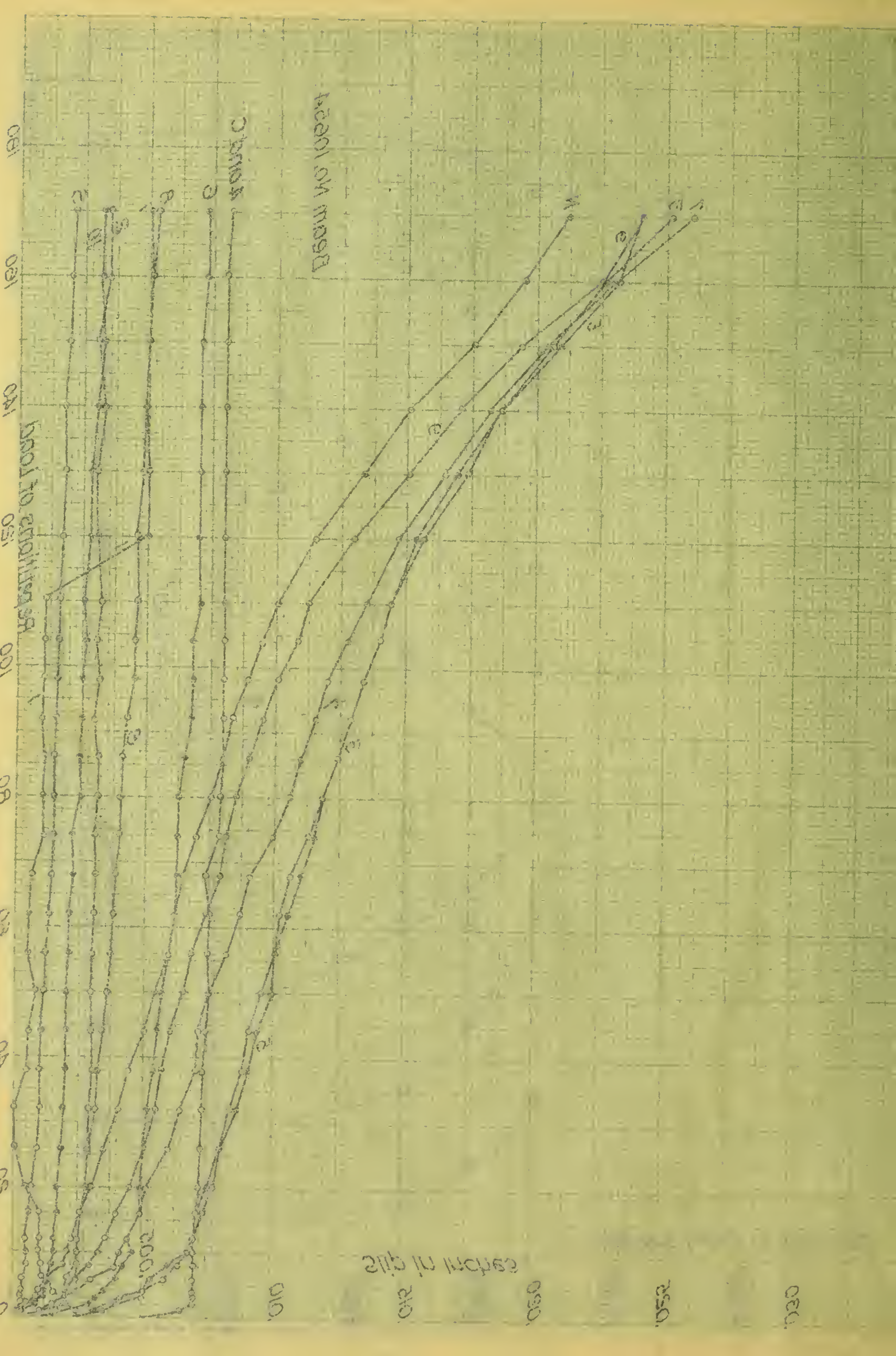
Applied Load in Pounds
20000
16000
12000
8000
4000
2'-0"
1065.3
1¼" Plain Round
10
8
6
4
2
1
3
5
7
9
Slip of Bar in Inches
0.004"
Albright, R.H.

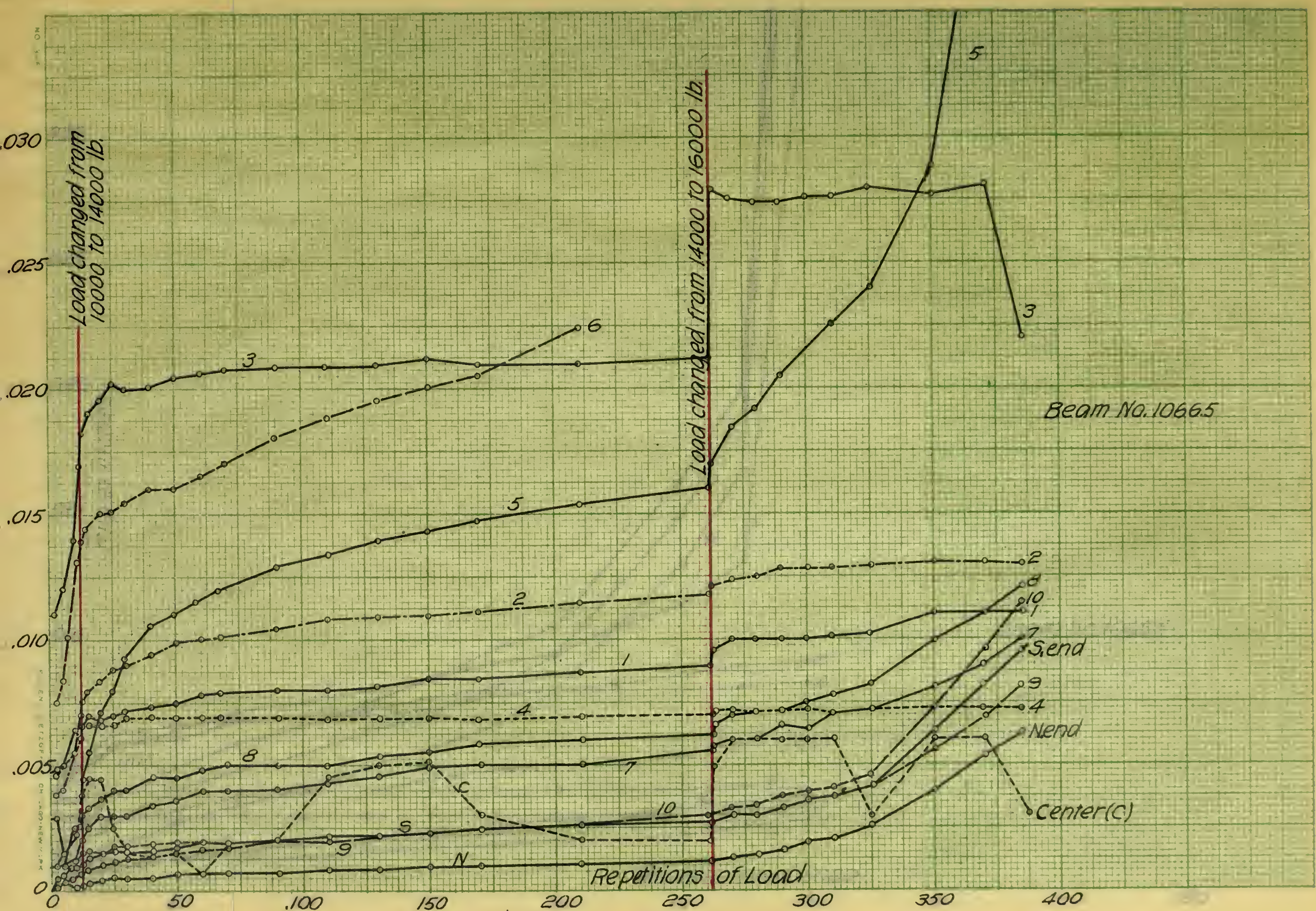


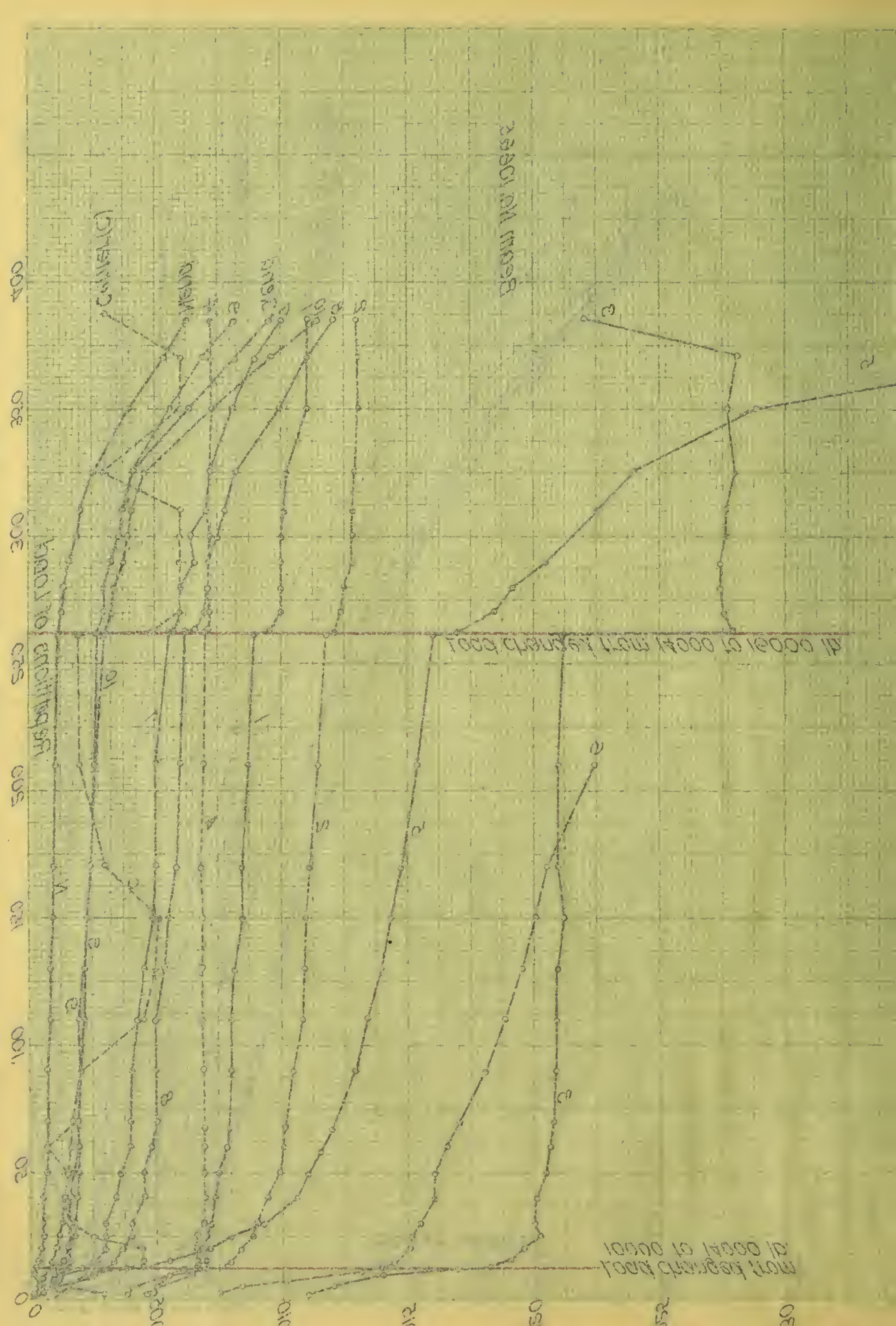
Slip of Bar in Inches
Load
1¾" Plain Round
10653
3'-0"
Applied Load in Pounds
4000
8000
12000
16000
20000

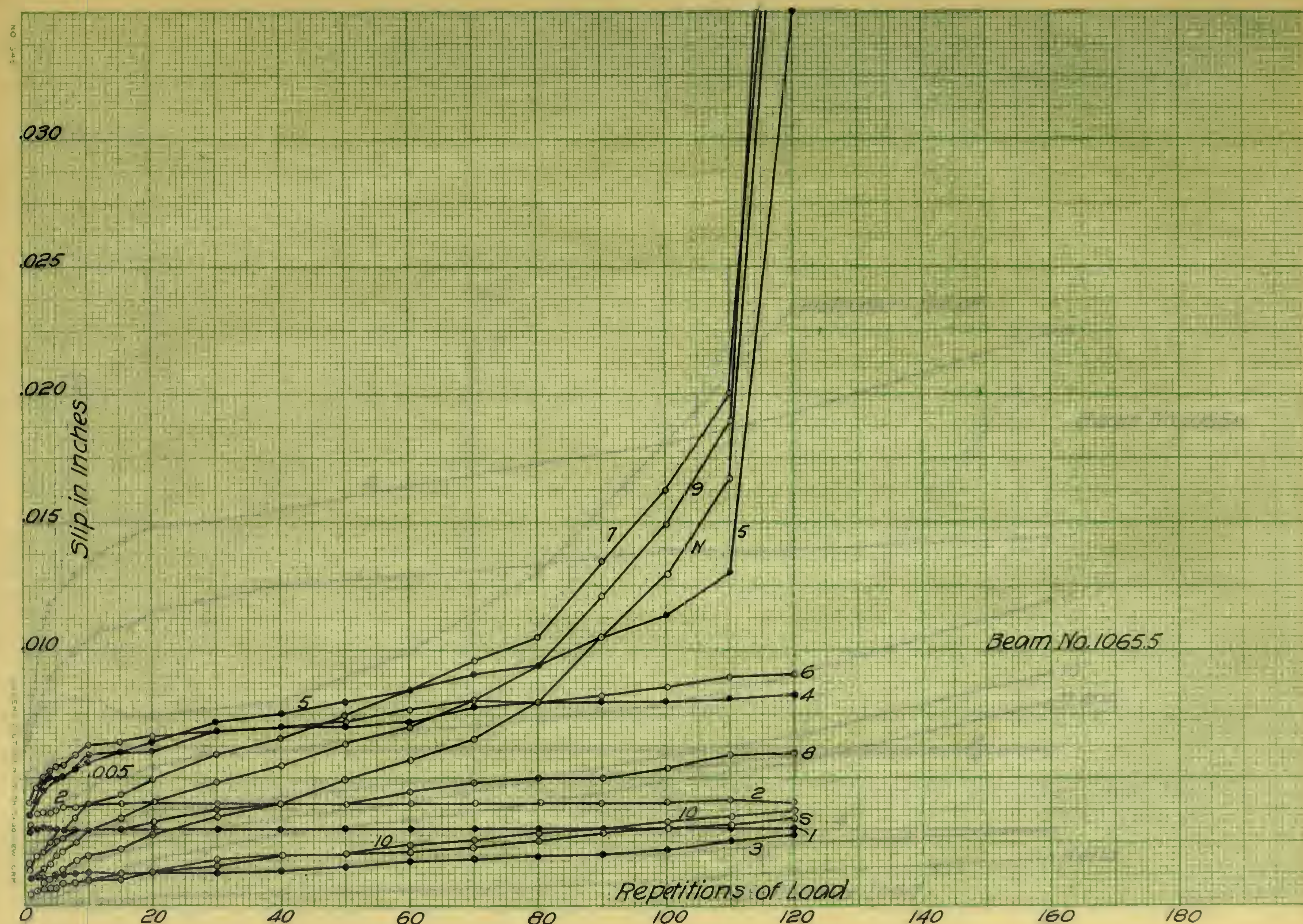


Beam No. 1065.4
Slip in Inches
Repetitions of Load
.030
.025
.020
.015
.010
.005
0
20
40
60
80
100
120
140
160
180
7
3
9
5
N
4 and C
6
8
1
2
10
S

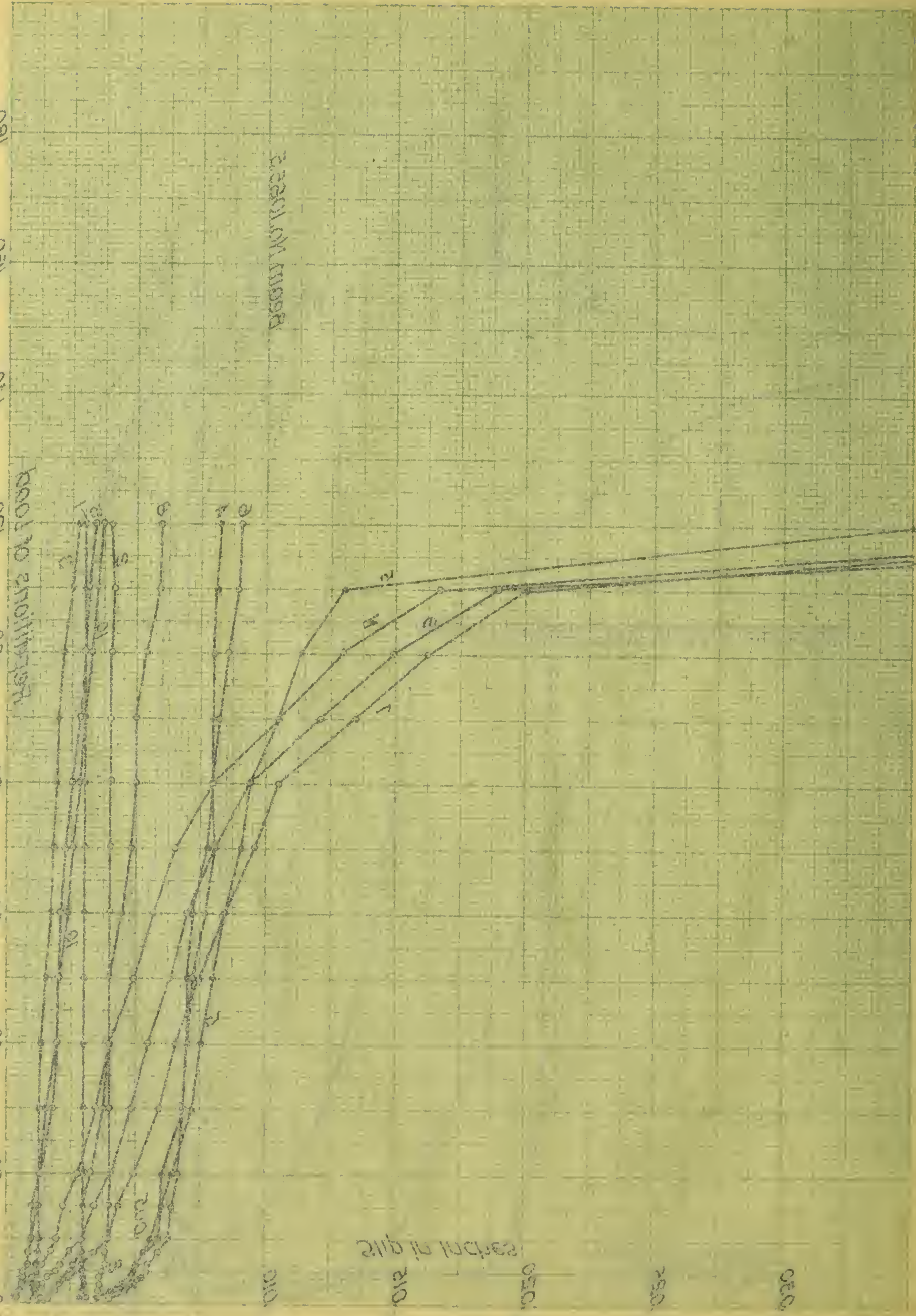

Slip in Inches
Repetitions of Load

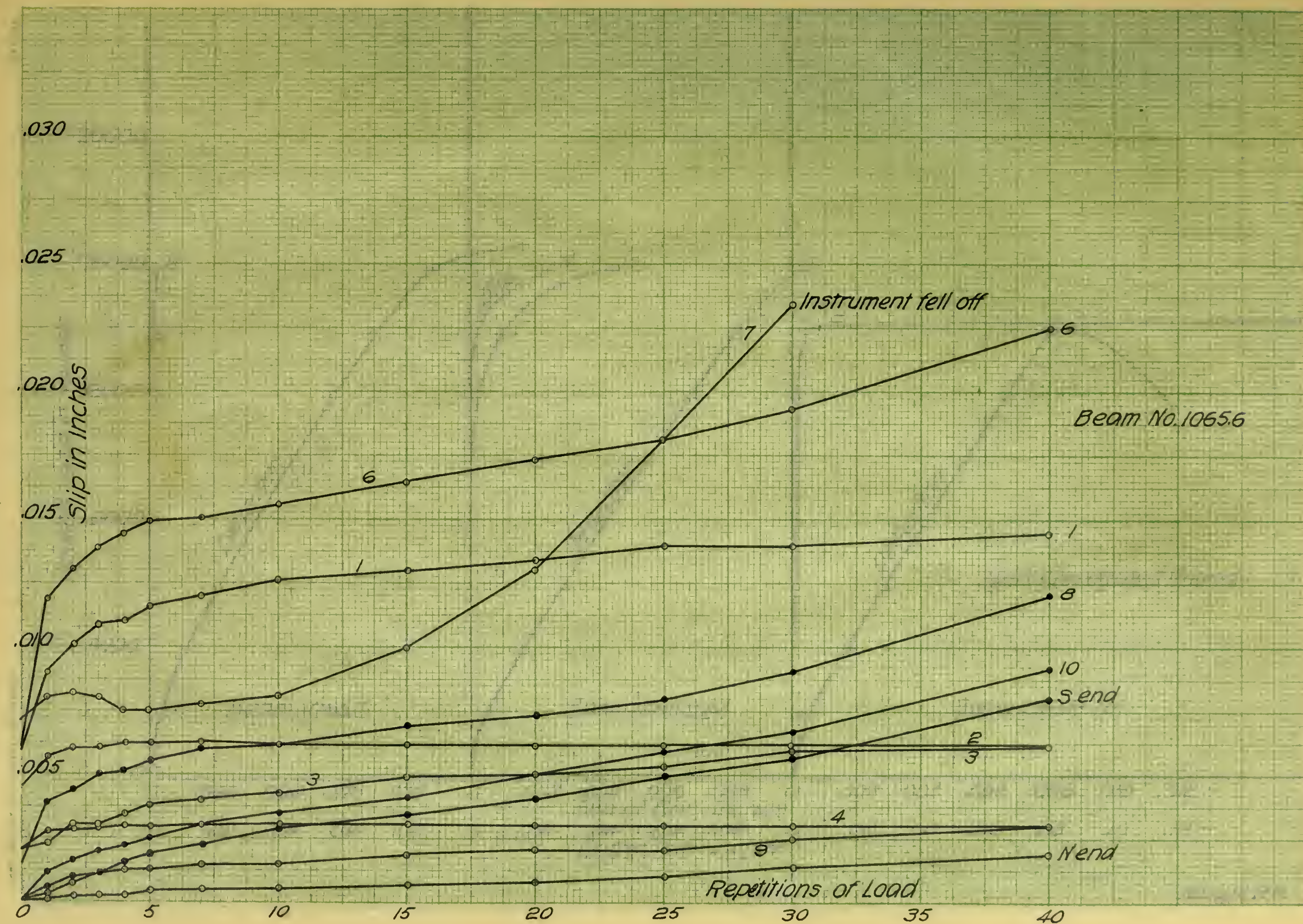

Beam No. 1066.5
Load changed from 10000 to 14000 lb.
Load changed from 14000 to 16000 lb.
Repetitions of Load
Center (C)
N end
S end
.030
.025
.020
.015
.010
.005
0
50
100
150
200
250
300
350
400

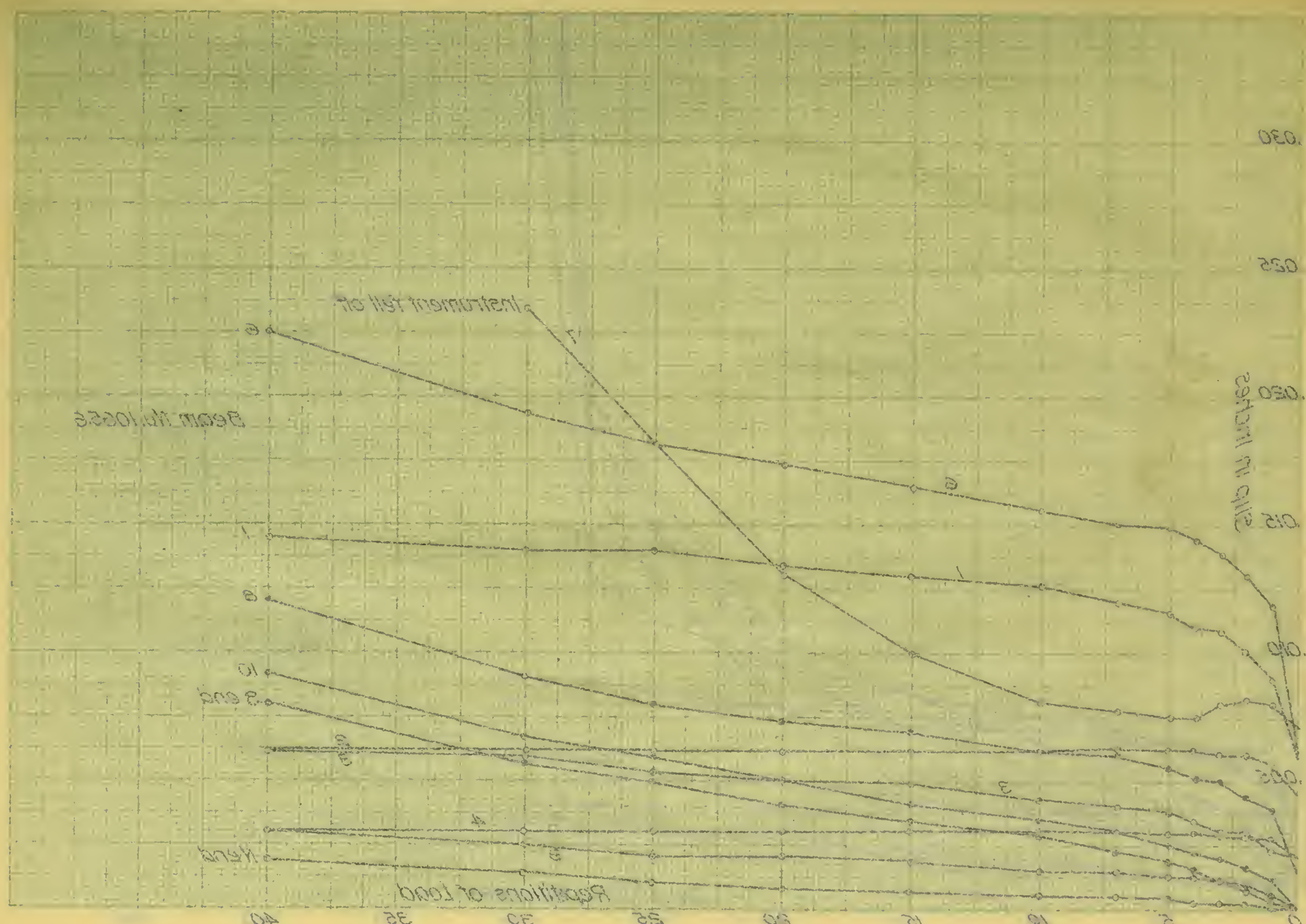




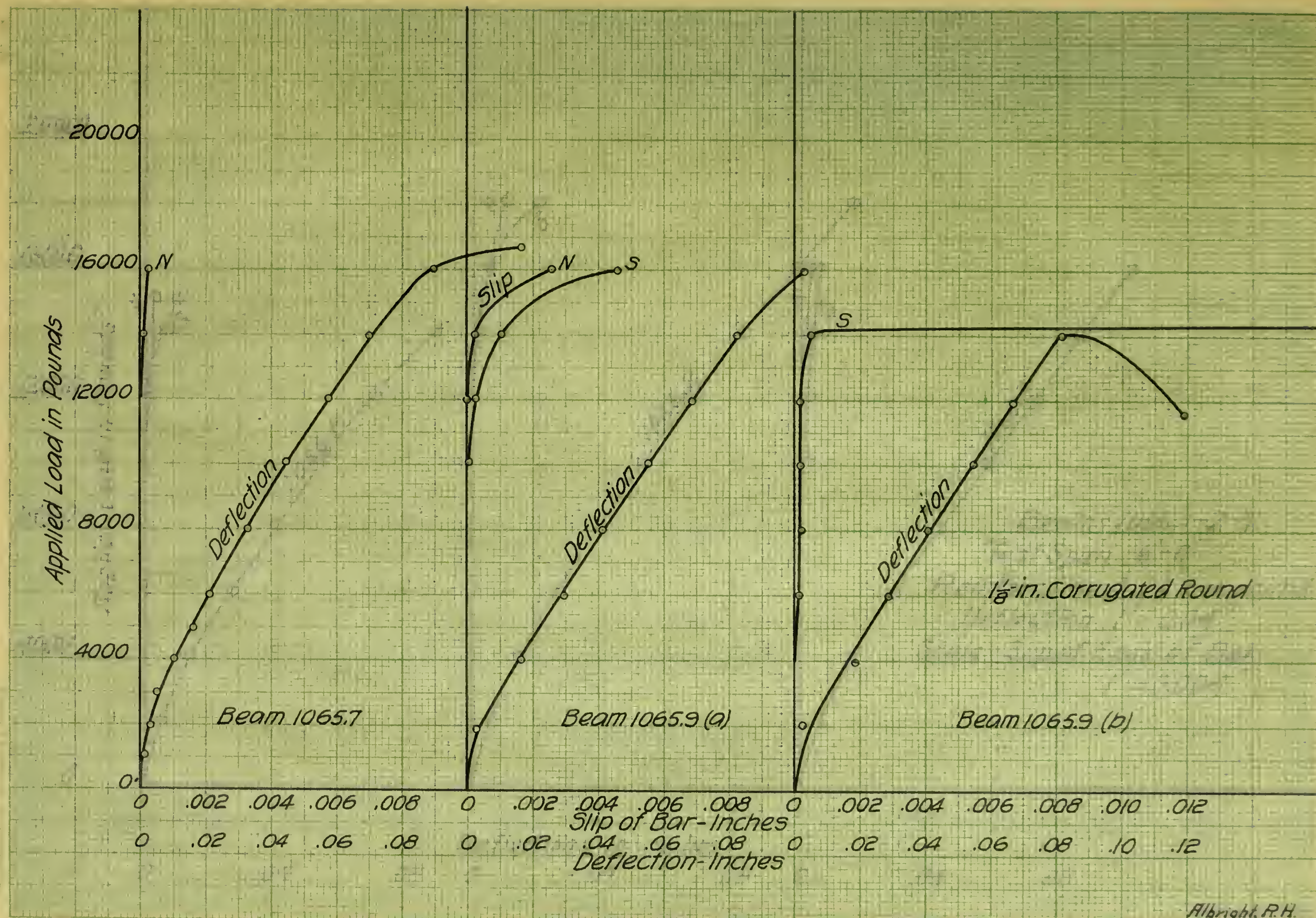
Beam No.1065.5
Slip in Inches
Repetitions of Load
.030
.025
.020
.015
.010
.005
0
20
40
60
80
100
120
140
160
180
7
9
N
5
6
4
8
2
10
5
1
3



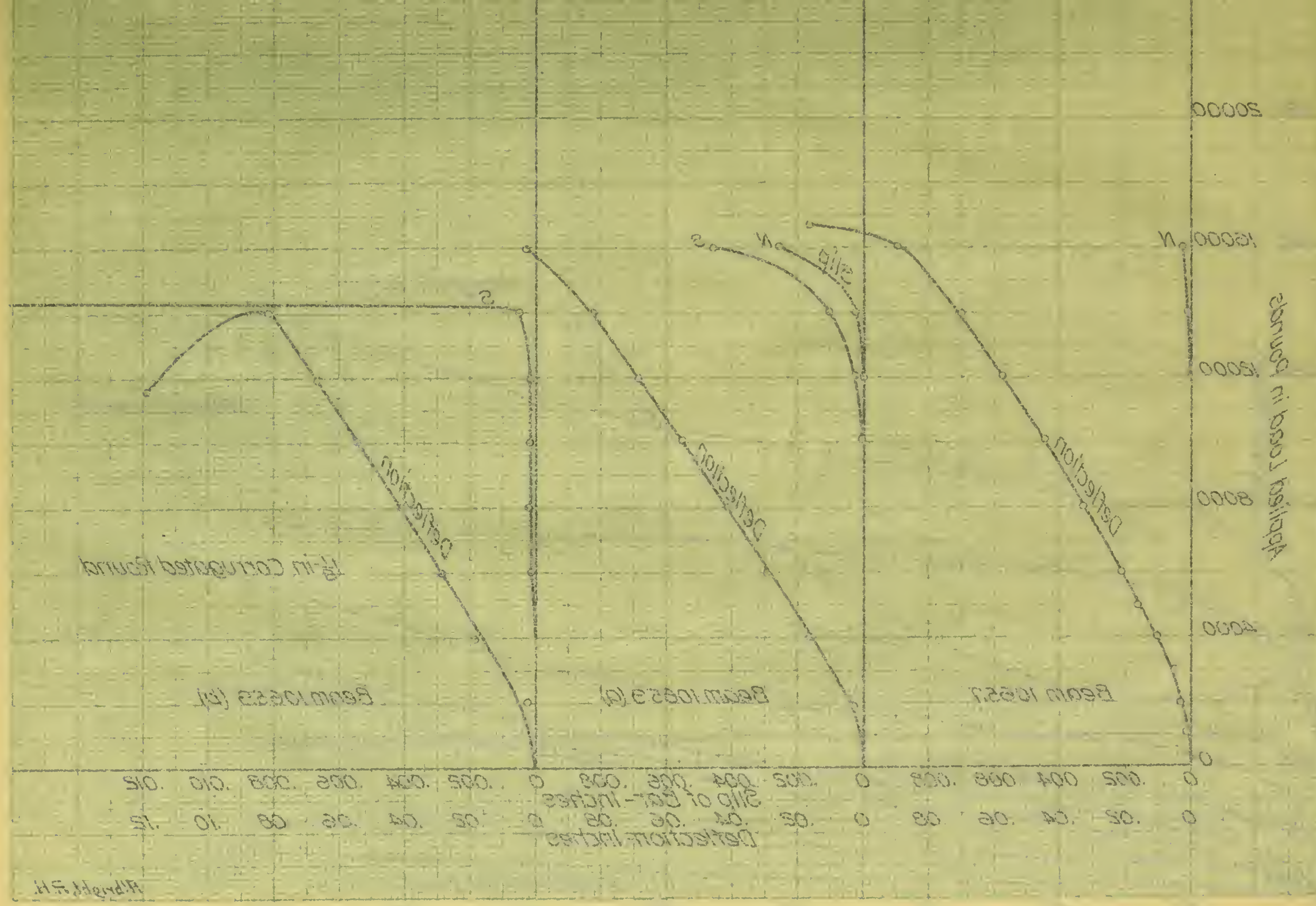

Beam No.1065.6
Instrument fell off
Slip in Inches
Repetitions of Load
.030
.025
.020
.015
.010
.005
0
5
10
15
20
25
30
35
40
6
1
7
8
10
S end
2
3
4
9
N end

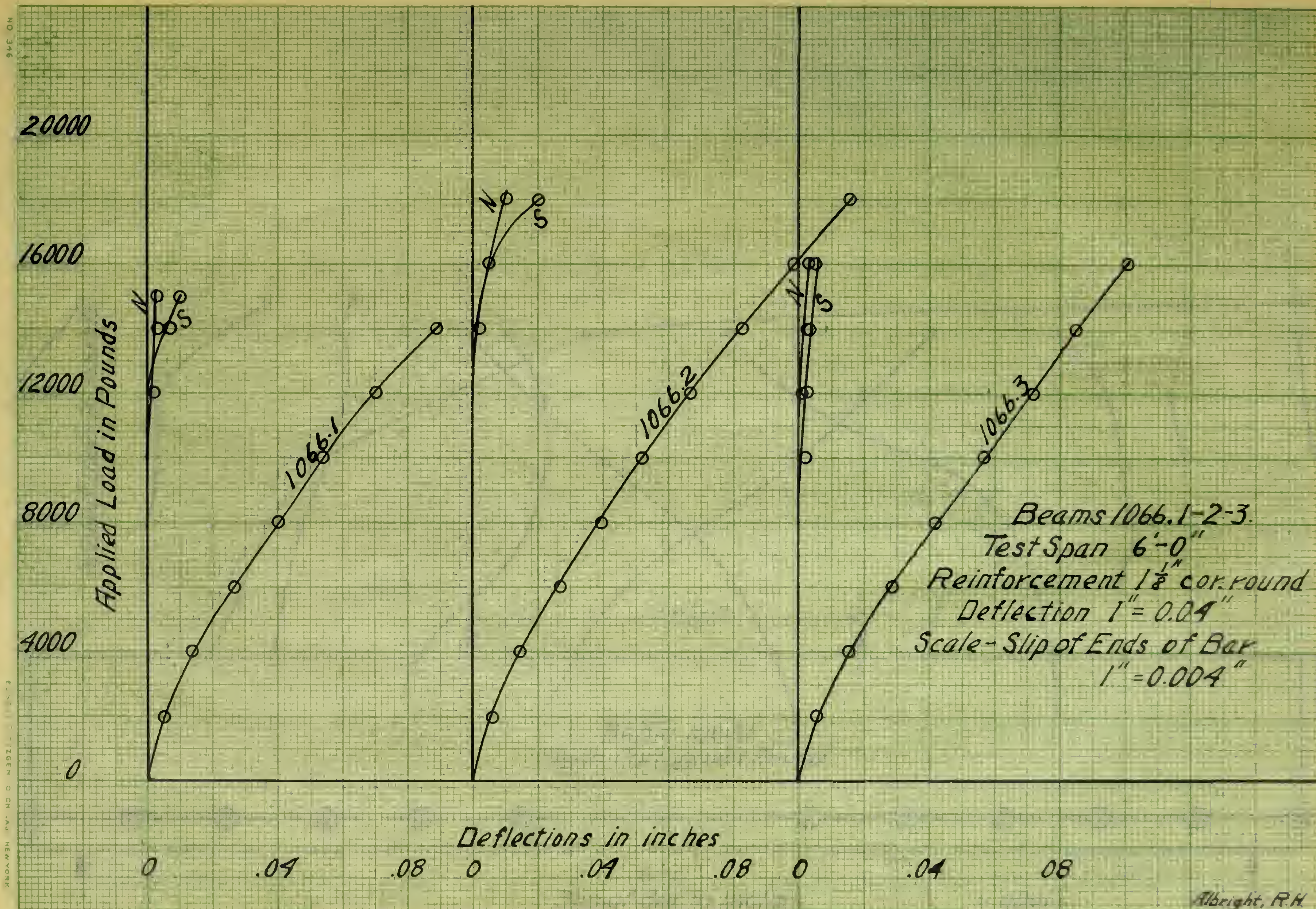


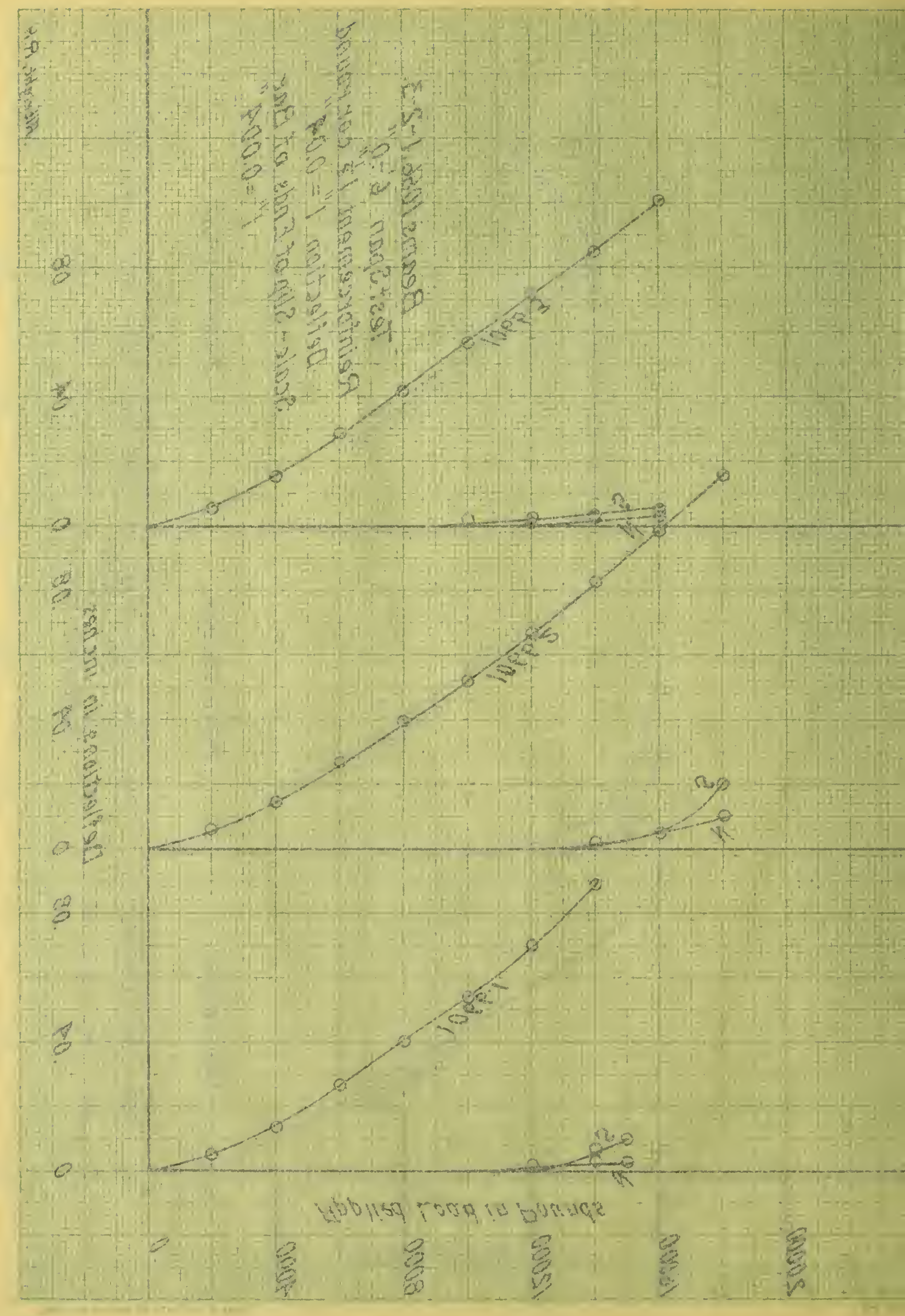
Slip in inches
Repetitions of Load
Instrument fell off

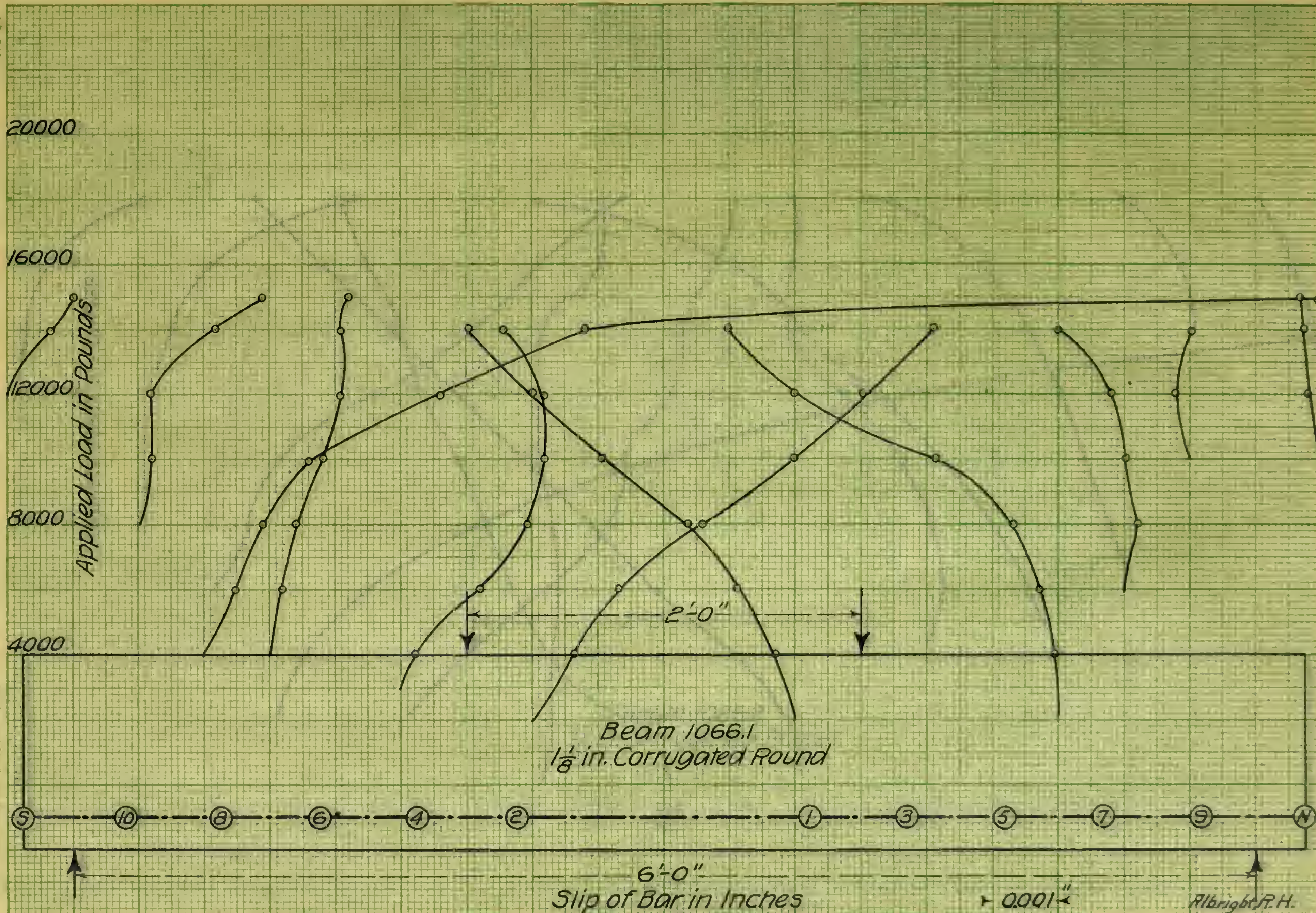


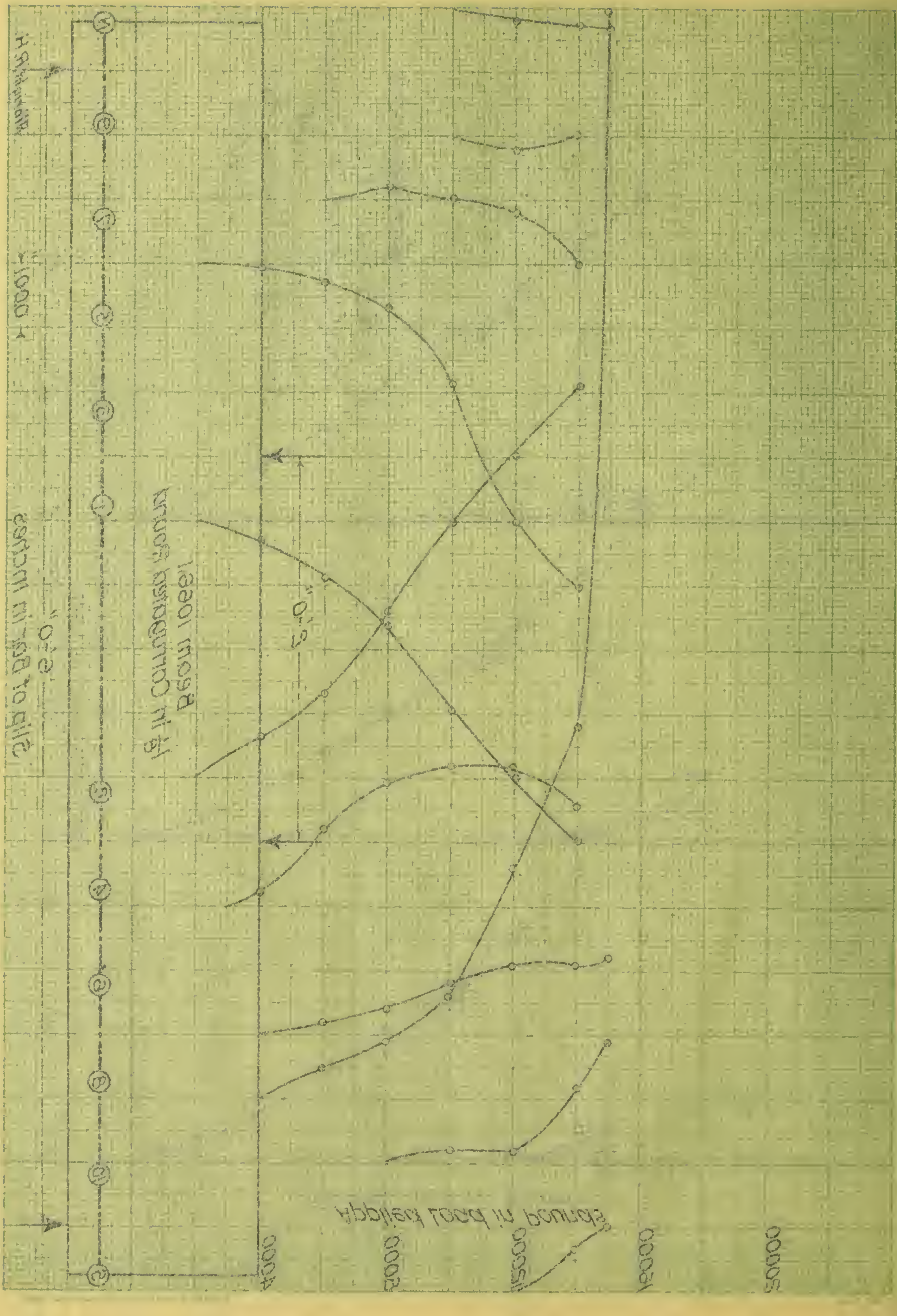
Applied Load in Pounds
20000
16000
12000
8000
4000
0
N
Slip
N
S
S
Deflection
Deflection
Deflection
Beam 1065.7
Beam 1065.9 (a)
Beam 1065.9 (b)
1⅛-in. Corrugated Round
0 .002 .004 .006 .008
0 .002 .004 .006 .008
0 .002 .004 .006 .008 .010 .012
Slip of Bar-Inches
0 .02 .04 .06 .08
0 .02 .04 .06 .08
0 .02 .04 .06 .08 .10 .12
Deflection-Inches
Albright, R.H.


Applied Load in Pounds
Beam 1065.7
Beam 1065.9 (a)
Beam 1065.9 (b)
Deflection
Slip
Slip of Bar - Inches
Deflection - Inches

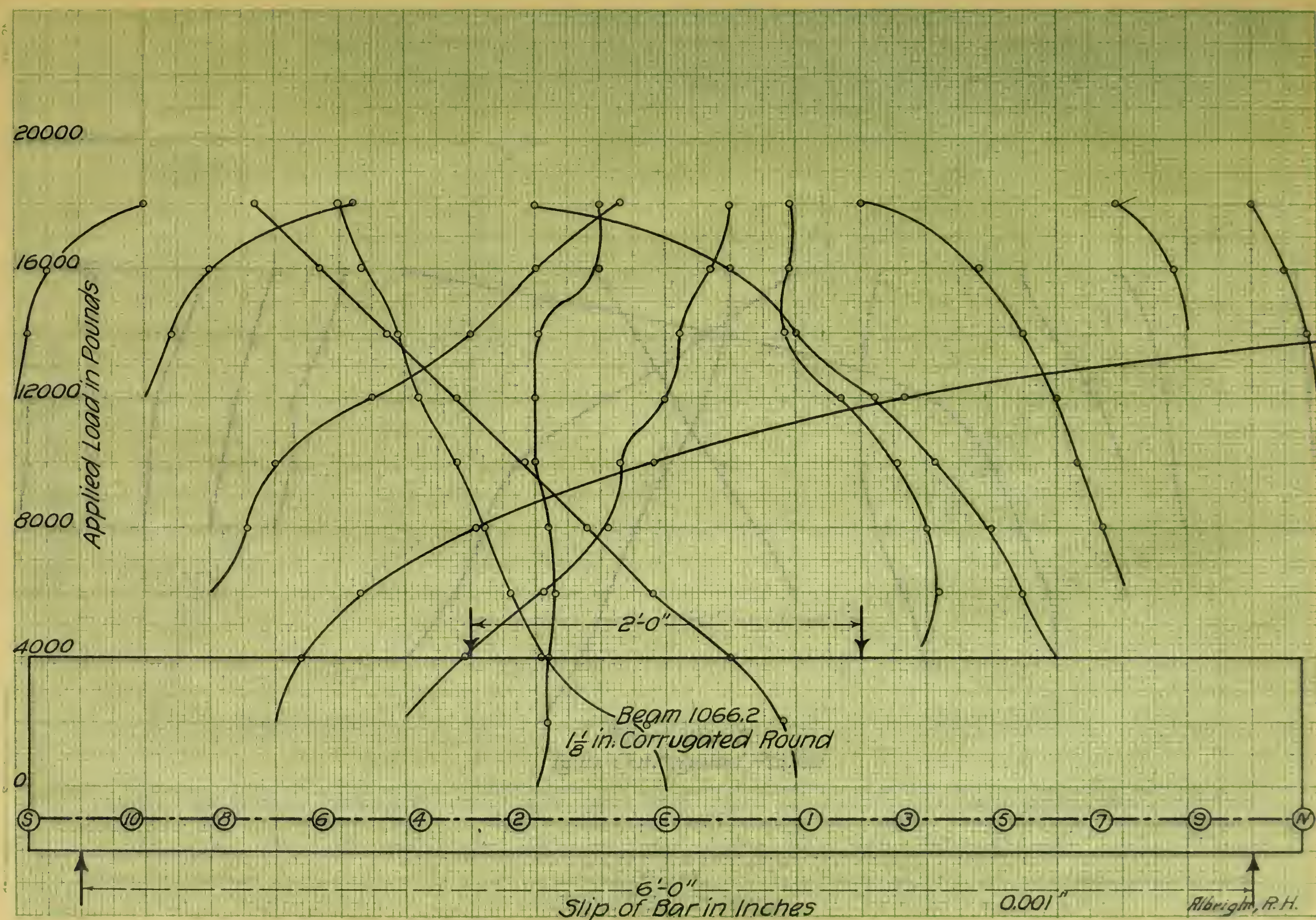

NO 346
20000
16000
12000
8000
4000
0
Applied Load in Pounds
N
S
1066.1
1066.2
1066.3
Beams 1066.1-2-3.
Test Span 6'-0"
Reinforcement 1⅛" cor. round
Deflection 1" = 0.04"
Scale - Slip of Ends of Bar
1" = 0.004"
Deflections in inches
0
.04
.08
Albright, R.H.

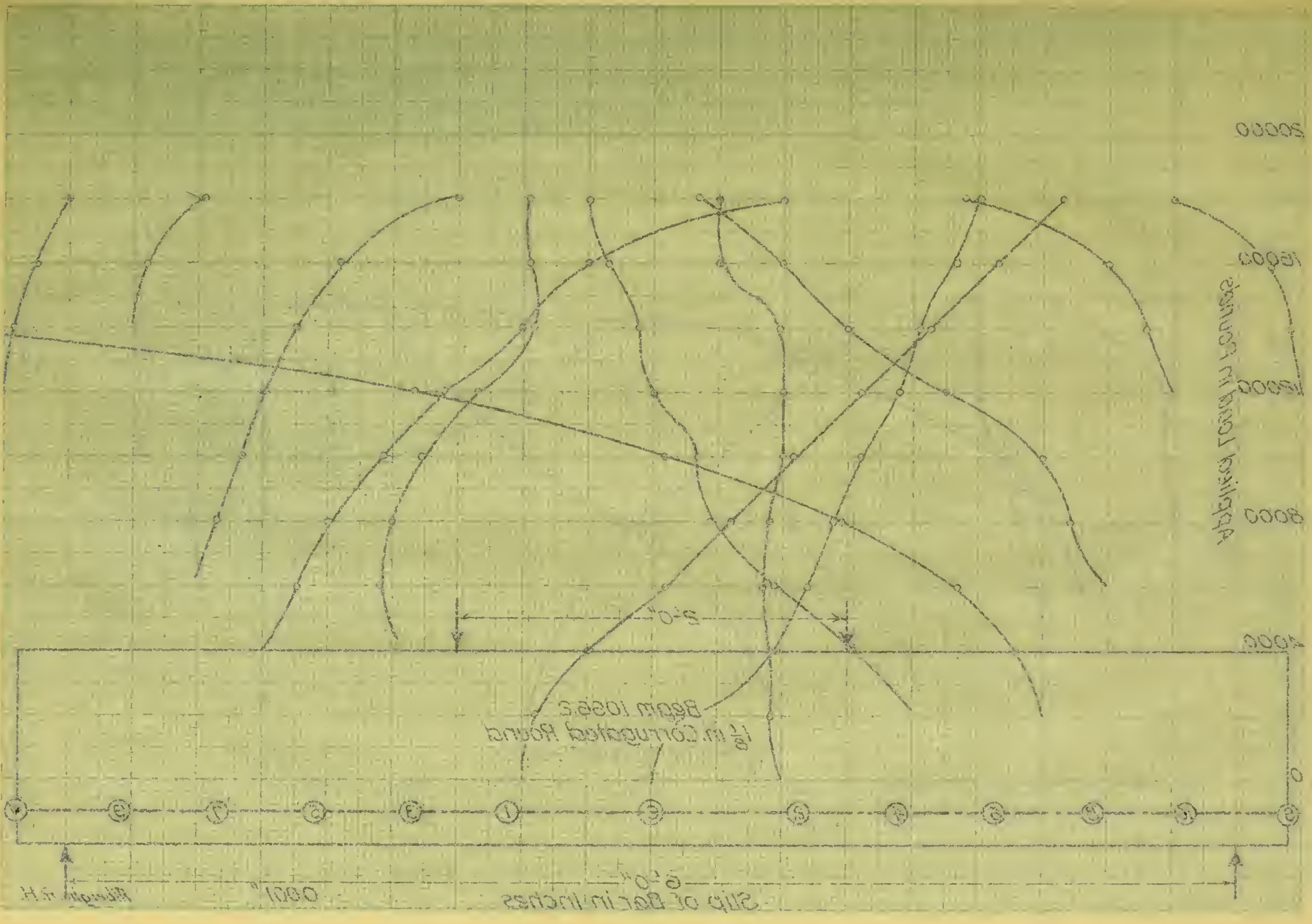

Applied Load in Pounds
Deflections in inches
Load 1
Load 2
Load 3

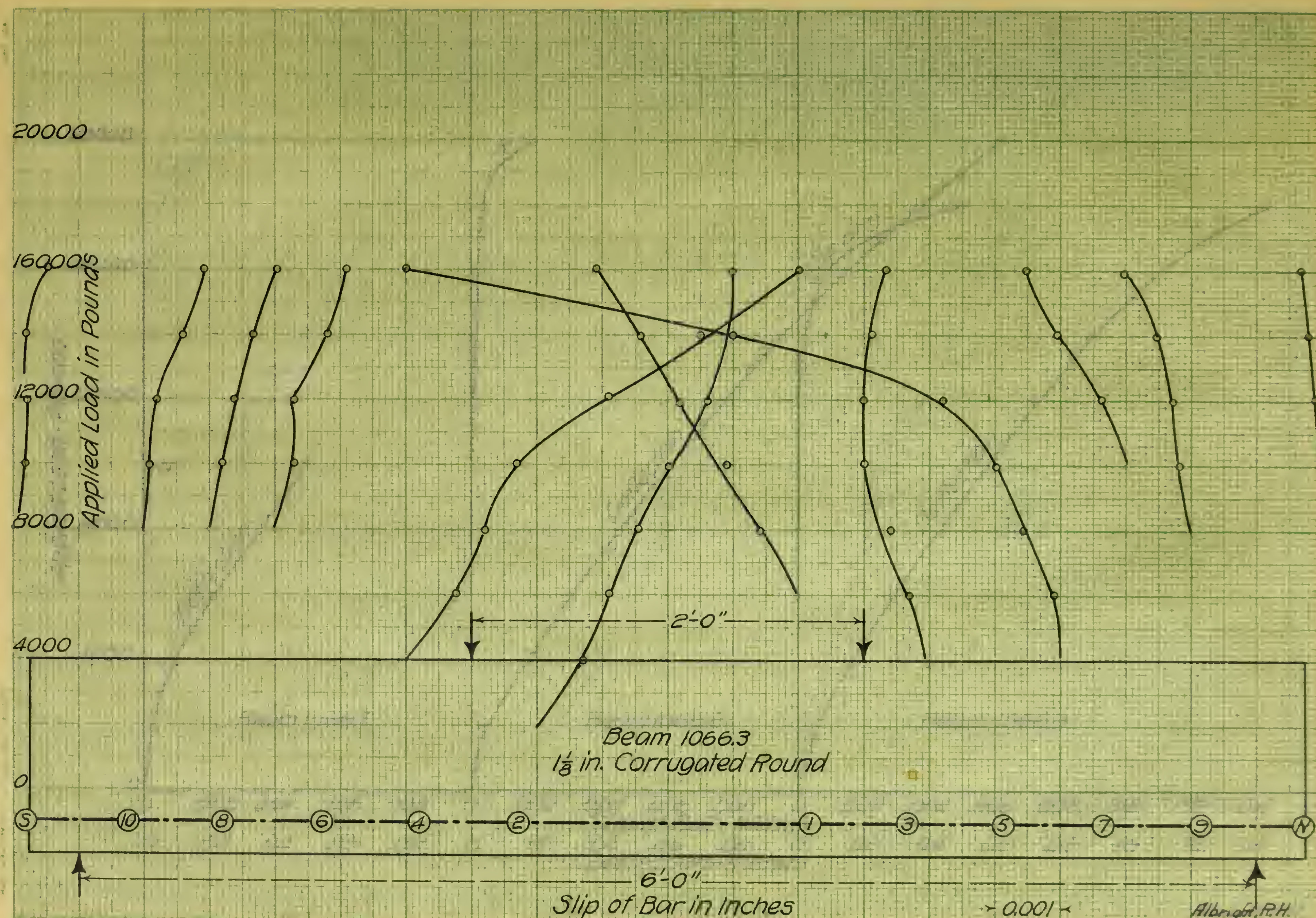

20000
16000
12000
8000
4000
Applied Load in Pounds
2'-0"
Beam 1066.1
1 1/8 in. Corrugated Round
S
10
8
6
4
2
1
3
5
7
9
N
6'-0"
Slip of Bar in Inches
0.001"
Albright R.H.

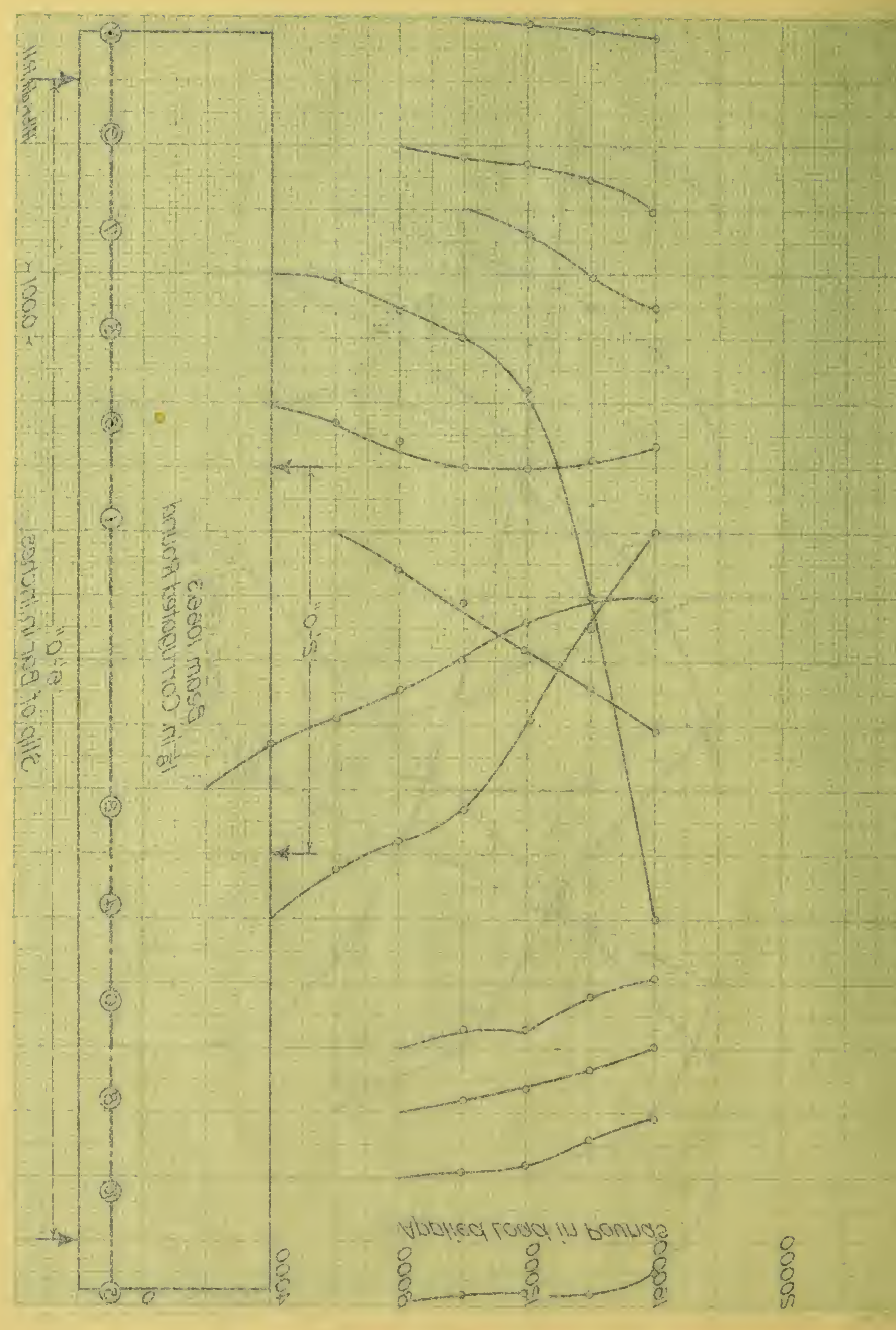


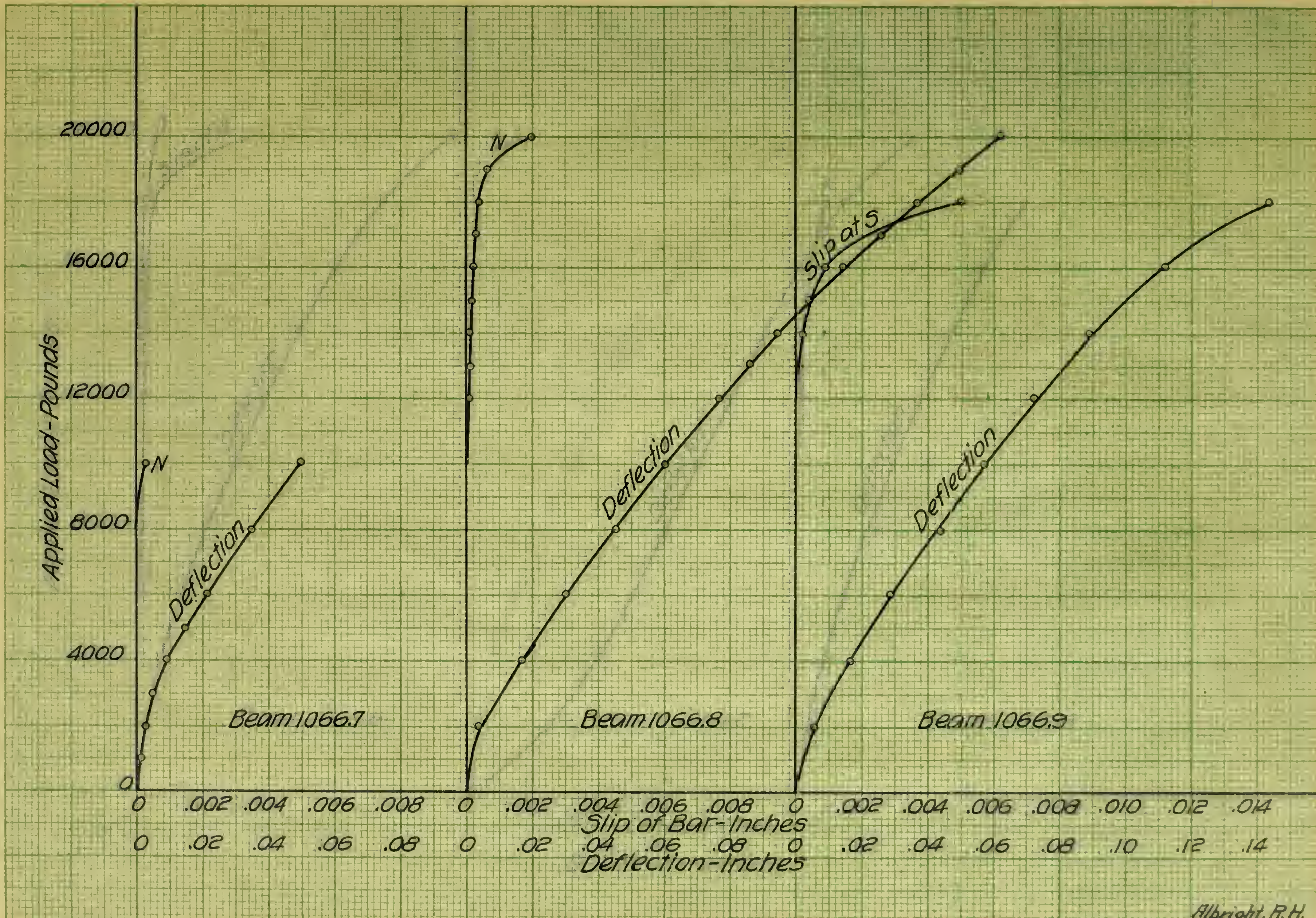
Applied Load in Pounds
Slip of Bar in Inches
1½ in Corrugated Round
6'-0"
2'-0"
4000
8000
12000
16000
20000

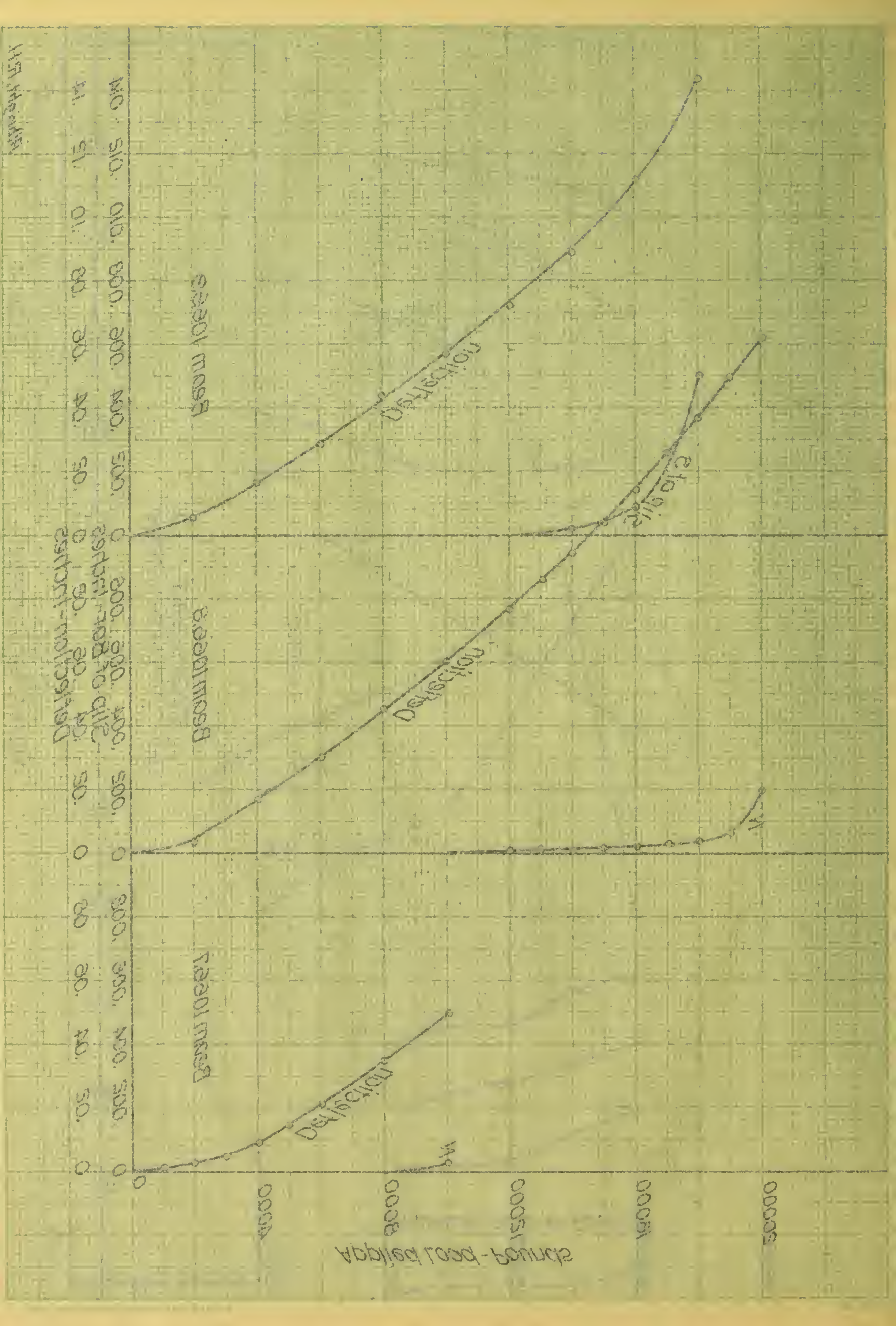

20000
16000
12000
8000
4000
0
Applied Load in Pounds
2'-0"
Beam 1066.2
$1\frac{1}{8}$ in. Corrugated Round
S
10
8
6
4
2
E
1
3
5
7
9
N
6'-0"
Slip of Bar in Inches
0.001"
Albright, R.H.


Applied Load in Pounds
Slip of Bar in Inches
Beam 1056.2
Corrugated Round
2'-0"
6'-0"
4000
8000
12000
16000
20000

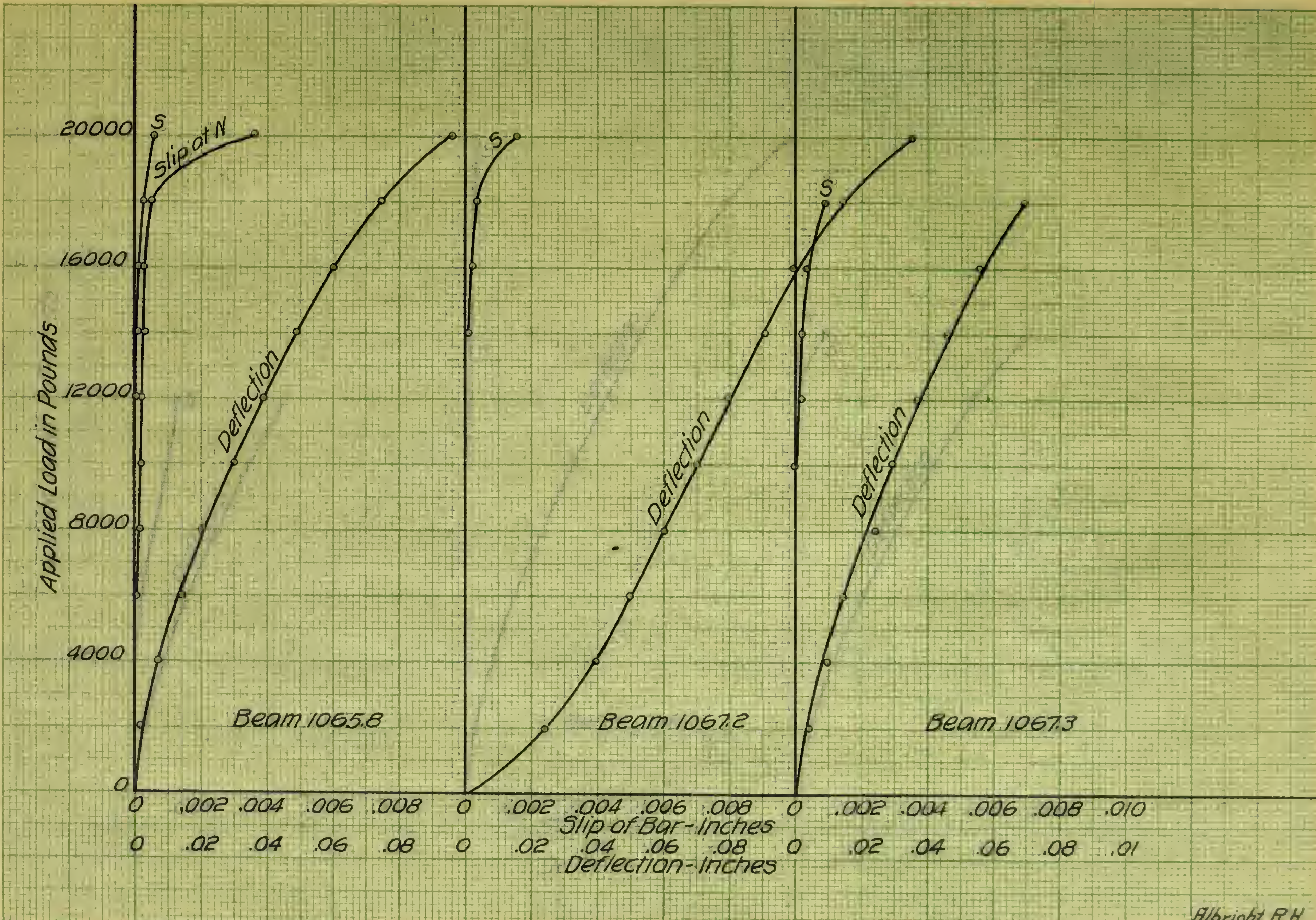

20000
16000
12000
8000
4000
0
Applied Load in Pounds
2'-0"
Beam 1066.3
1⅛ in. Corrugated Round
S
10
8
6
4
2
1
3
5
7
9
N
6'-0"
Slip of Bar in Inches
0.001
Albright, R.H.


Applied Load in Pounds
4000
8000
12000
16000
20000
Slip of Bar in Inches

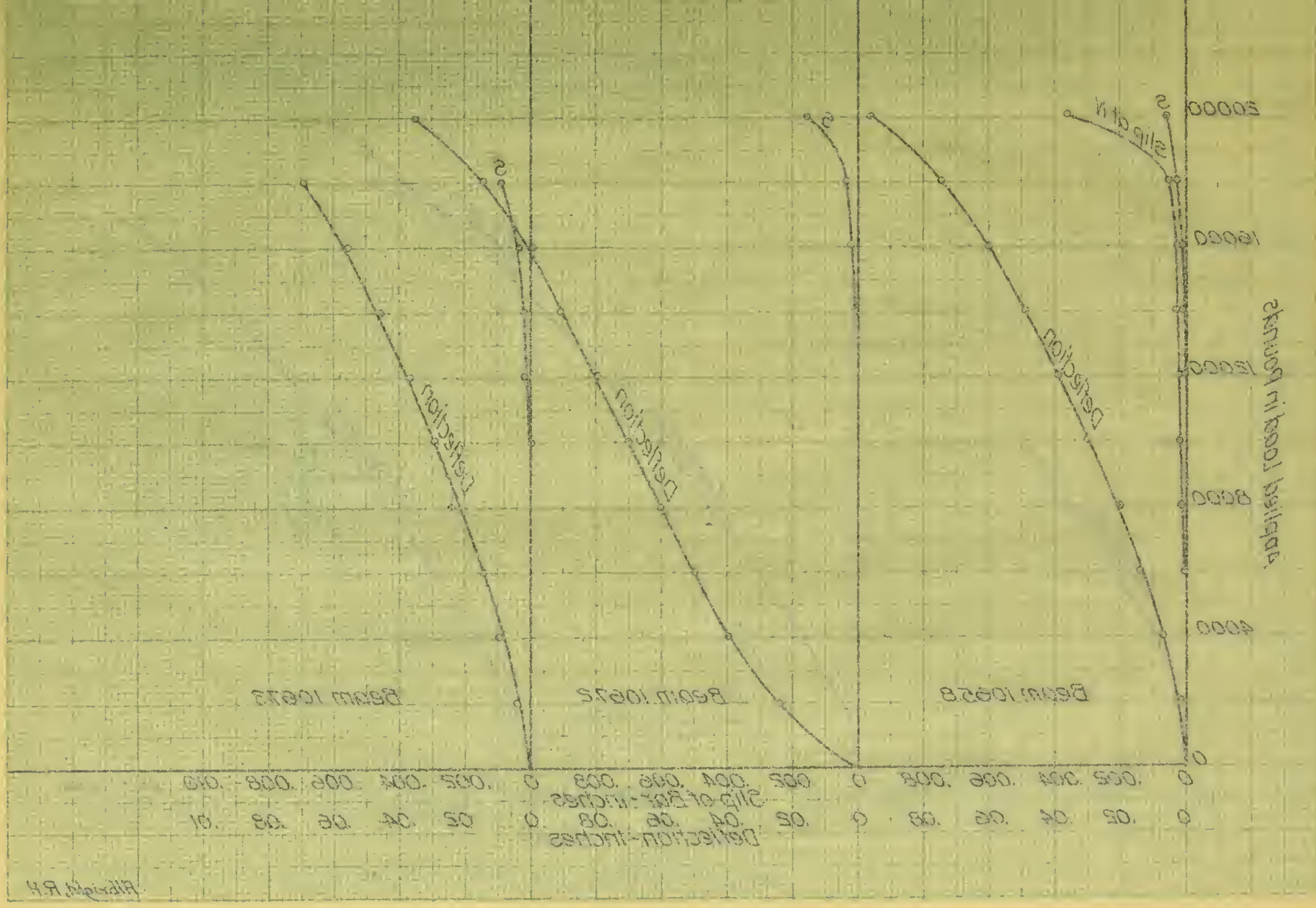

Applied Load-Pounds
20000
16000
12000
8000
4000
0
N
Deflection
Beam 1066.7
N
Deflection
Beam 1066.8
Slip at S
Deflection
Beam 1066.9
0 .002 .004 .006 .008 0 .002 .004 .006 .008 0 .002 .004 .006 .008 .010 .012 .014
Slip of Bar-Inches
0 .02 .04 .06 .08 0 .02 .04 .06 .08 0 .02 .04 .06 .08 .10 .12 .14
Deflection-Inches
Albright, R.H.

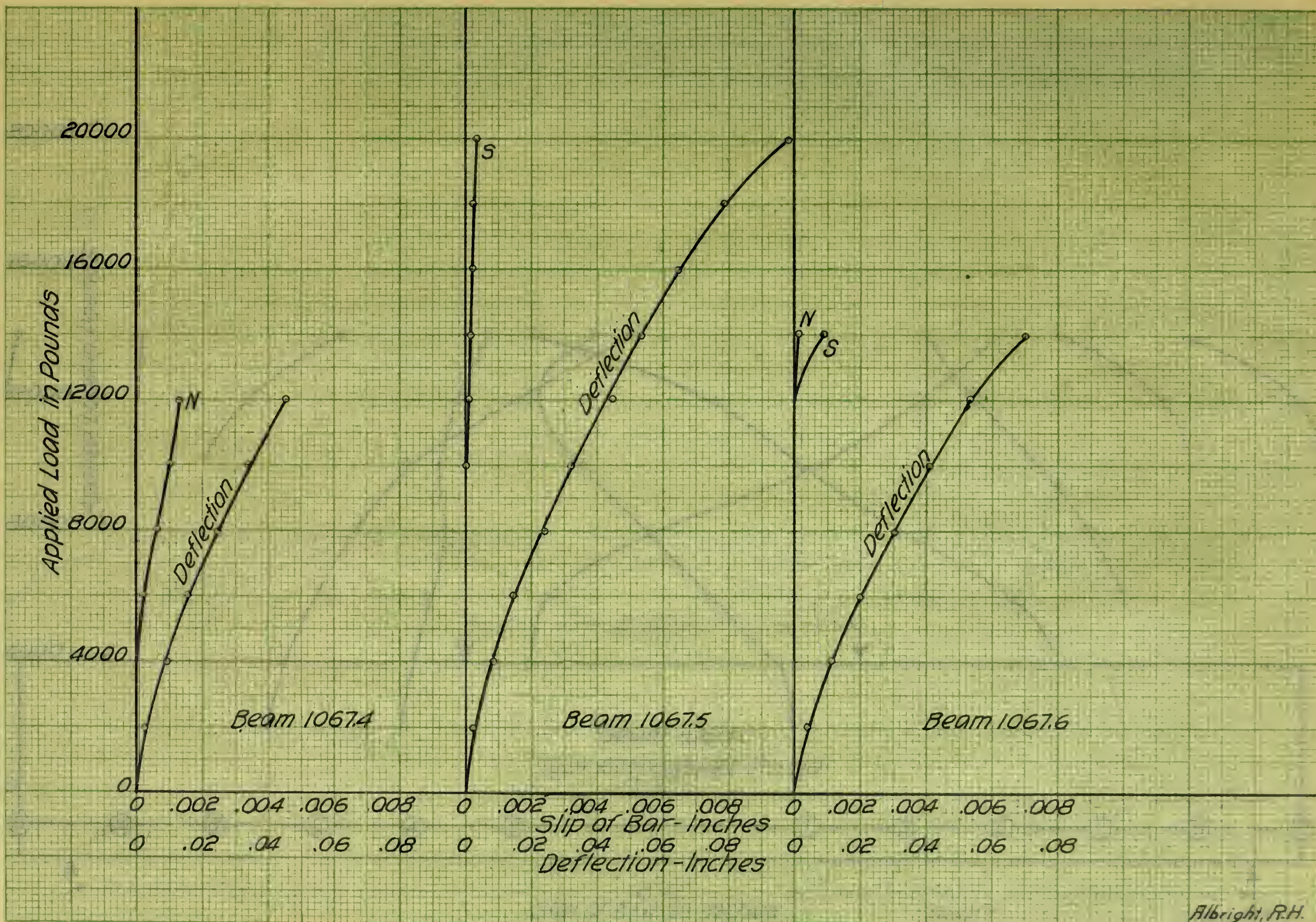


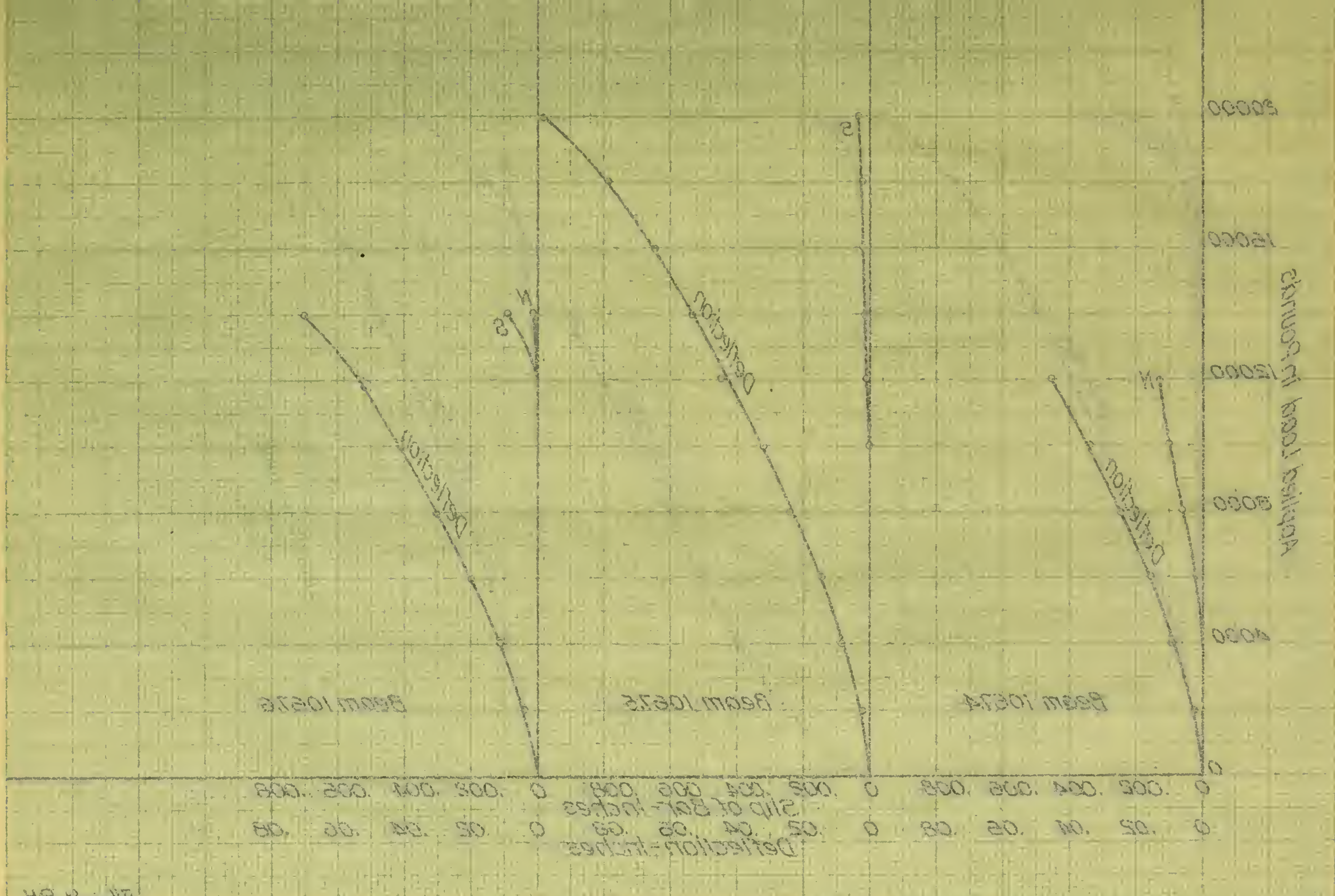
Applied Load - Pounds
Deflection - Inches
Slip of Bar - Inches
Deflection
Deflection
Deflection
Slip

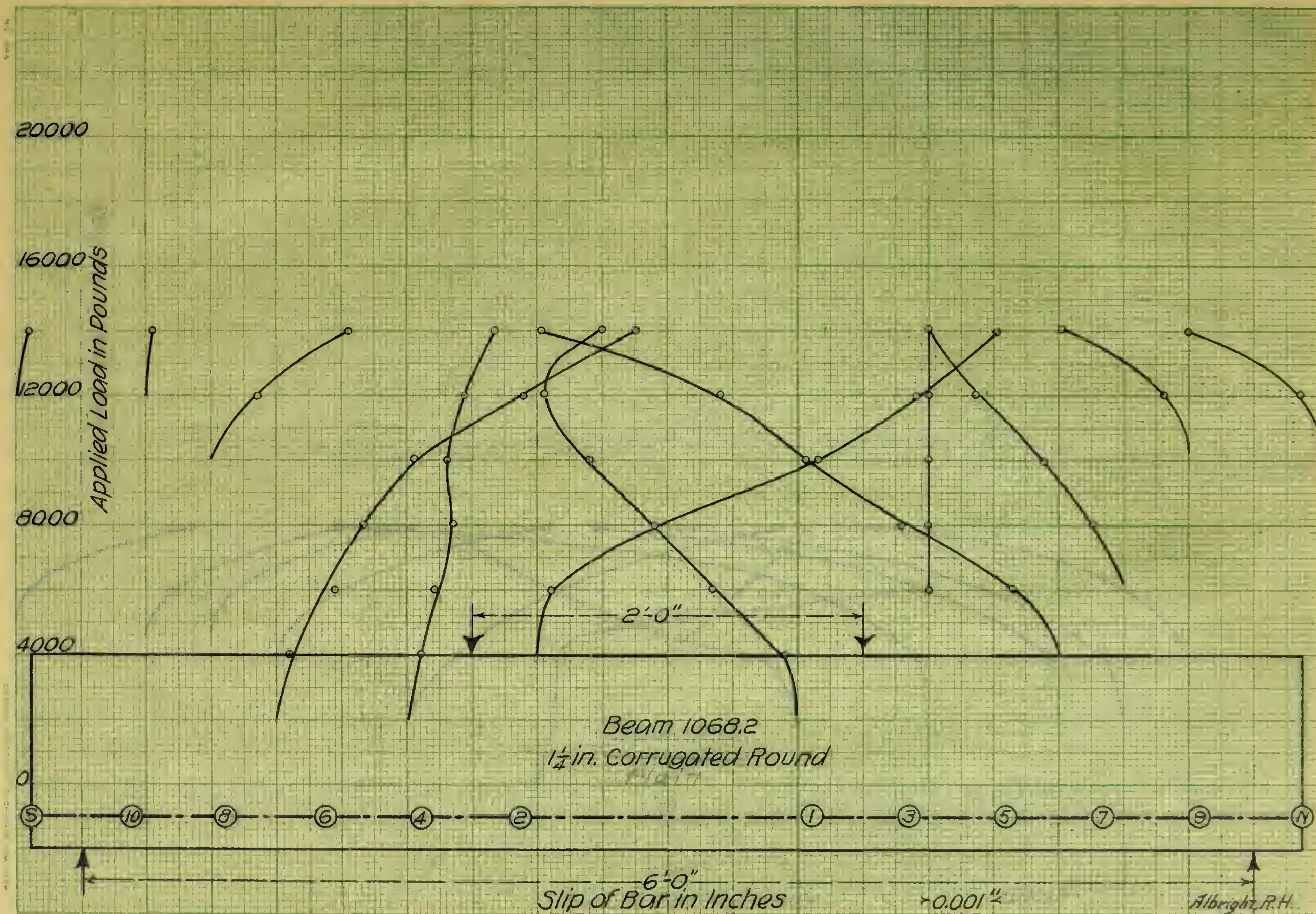


Applied Load in Pounds
20000
16000
12000
8000
4000
0
S
Slip at N
Deflection
Beam 1065.8
S
Deflection
Beam 1067.2
S
Deflection
Beam 1067.3
0 .002 .004 .006 .008 0 .002 .004 .006 .008 0 .002 .004 .006 .008 .010
Slip of Bar - Inches
0 .02 .04 .06 .08 0 .02 .04 .06 .08 0 .02 .04 .06 .08 .01
Deflection - Inches
Albright, R.H.

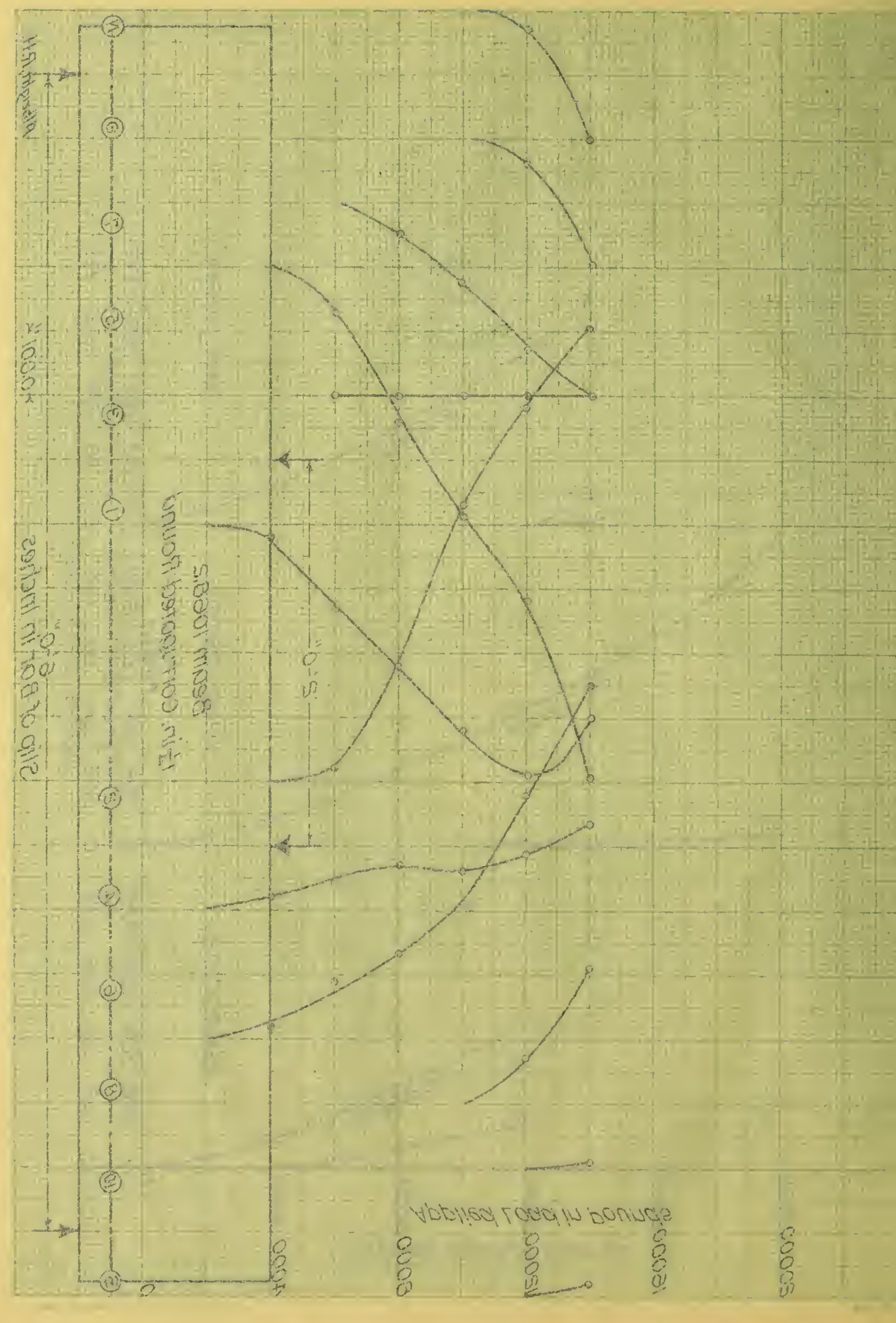

Beam 10658
Beam 10672
Beam 10673
Deflection
Slip at N
S
Applied Load in Pounds
0
4000
8000
12000
16000
20000
Slip of Bar-inches
Deflection-inches
0 .002 .004 .006 .008
0 .02 .04 .06 .08 .10
0 .002 .004 .006 .008 .010

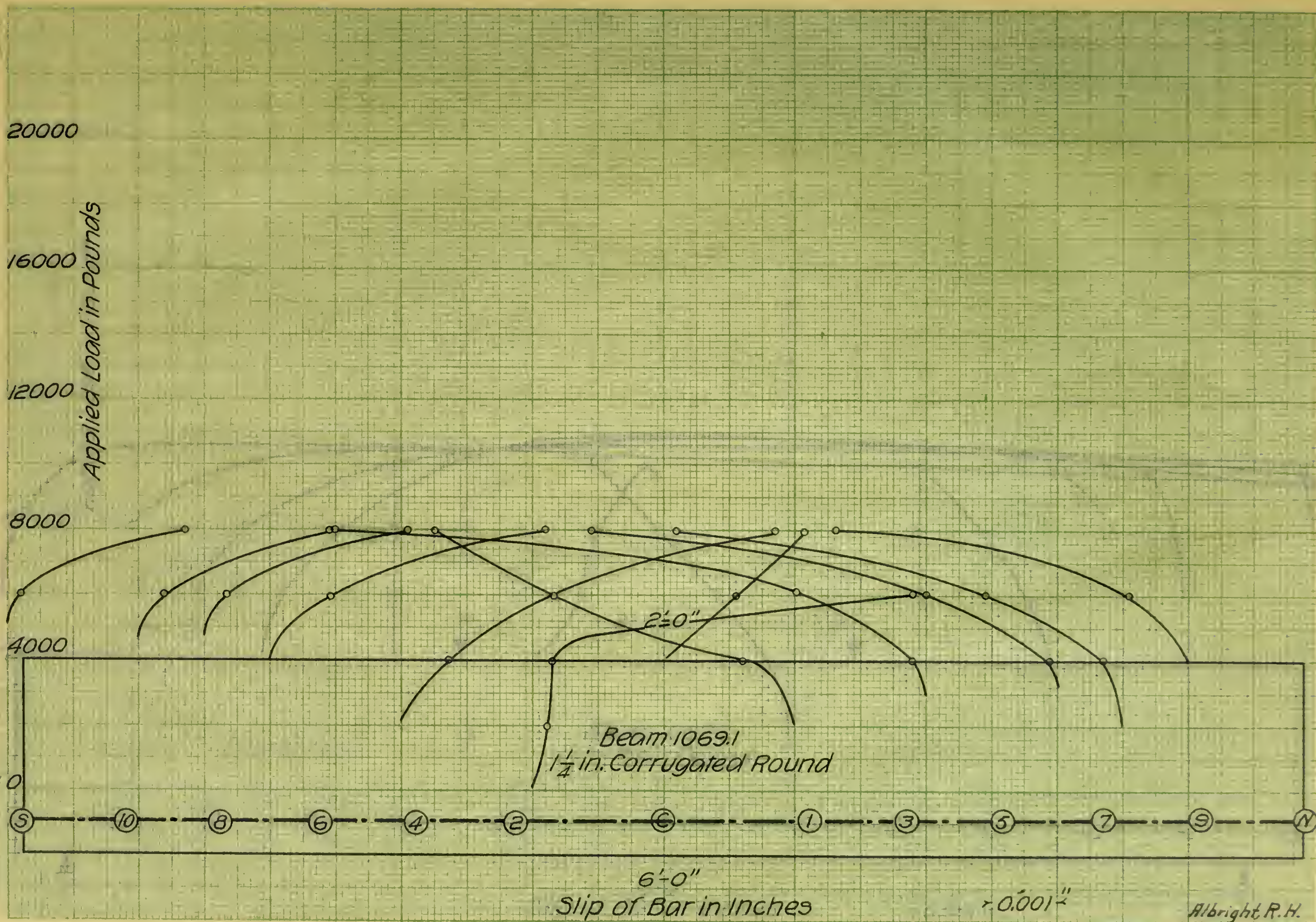

20000
16000
12000
8000
4000
0
Applied Load in Pounds
N
Deflection
Beam 1067.4
S
Deflection
Beam 1067.5
N
S
Deflection
Beam 1067.6
0 .002 .004 .006 .008
0 .002 .004 .006 .008
0 .002 .004 .006 .008
Slip of Bar - Inches
0 .02 .04 .06 .08
0 .02 .04 .06 .08
0 .02 .04 .06 .08
Deflection - Inches
Albright, R.H.


Beam 10524
Beam 10525
Beam 10526
Deflection
Applied Load in Pounds
Slip of Bar-Inches
Deflection-Inches
0
4000
8000
12000
16000
20000
S
N

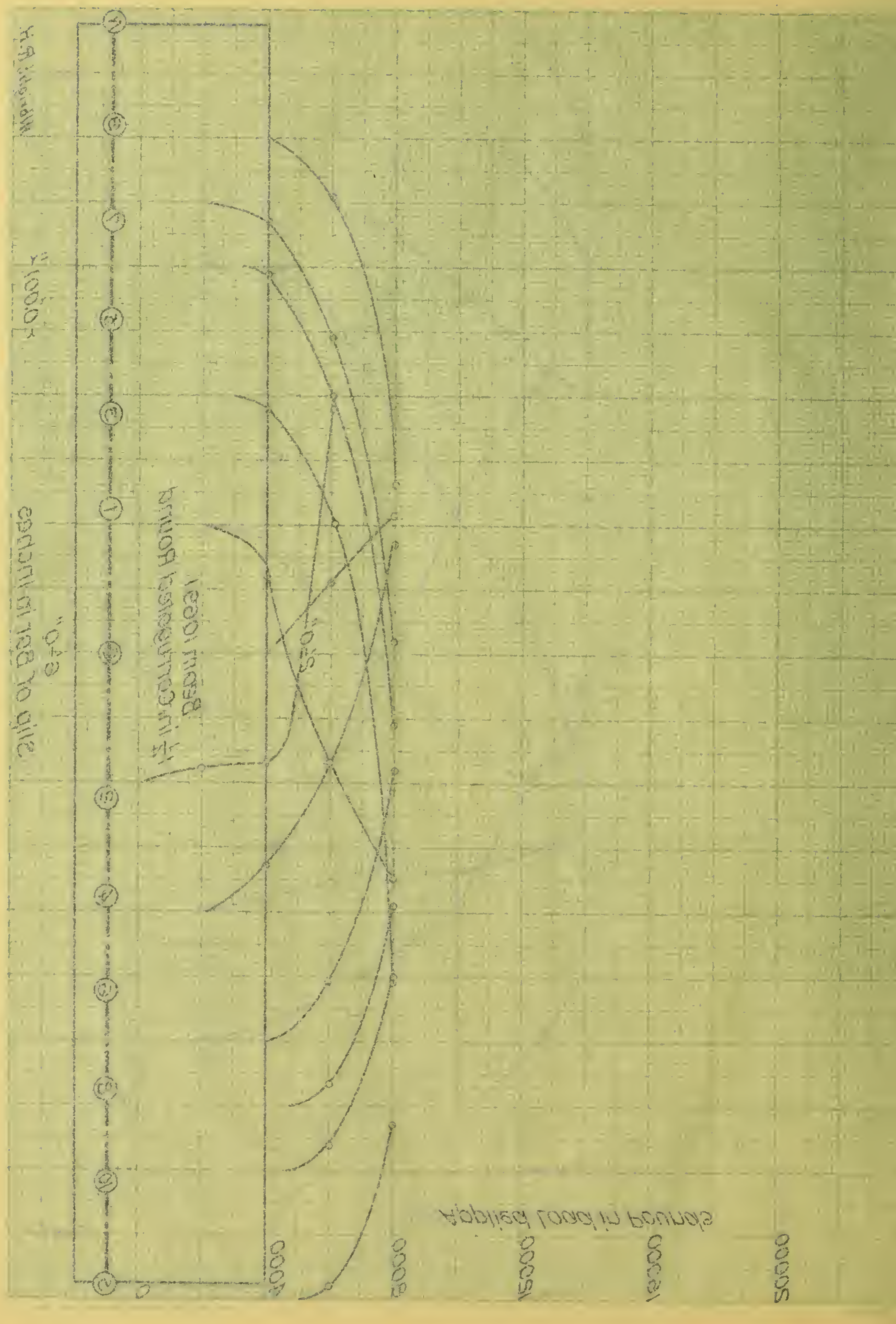


20000
16000
12000
8000
4000
0
Applied Load in Pounds
2'-0"
Beam 1068.2
1¼ in. Corrugated Round
S
10
8
6
4
2
1
3
5
7
9
N
6'-0"
Slip of Bar in Inches
0.001"
Albright, R.H.

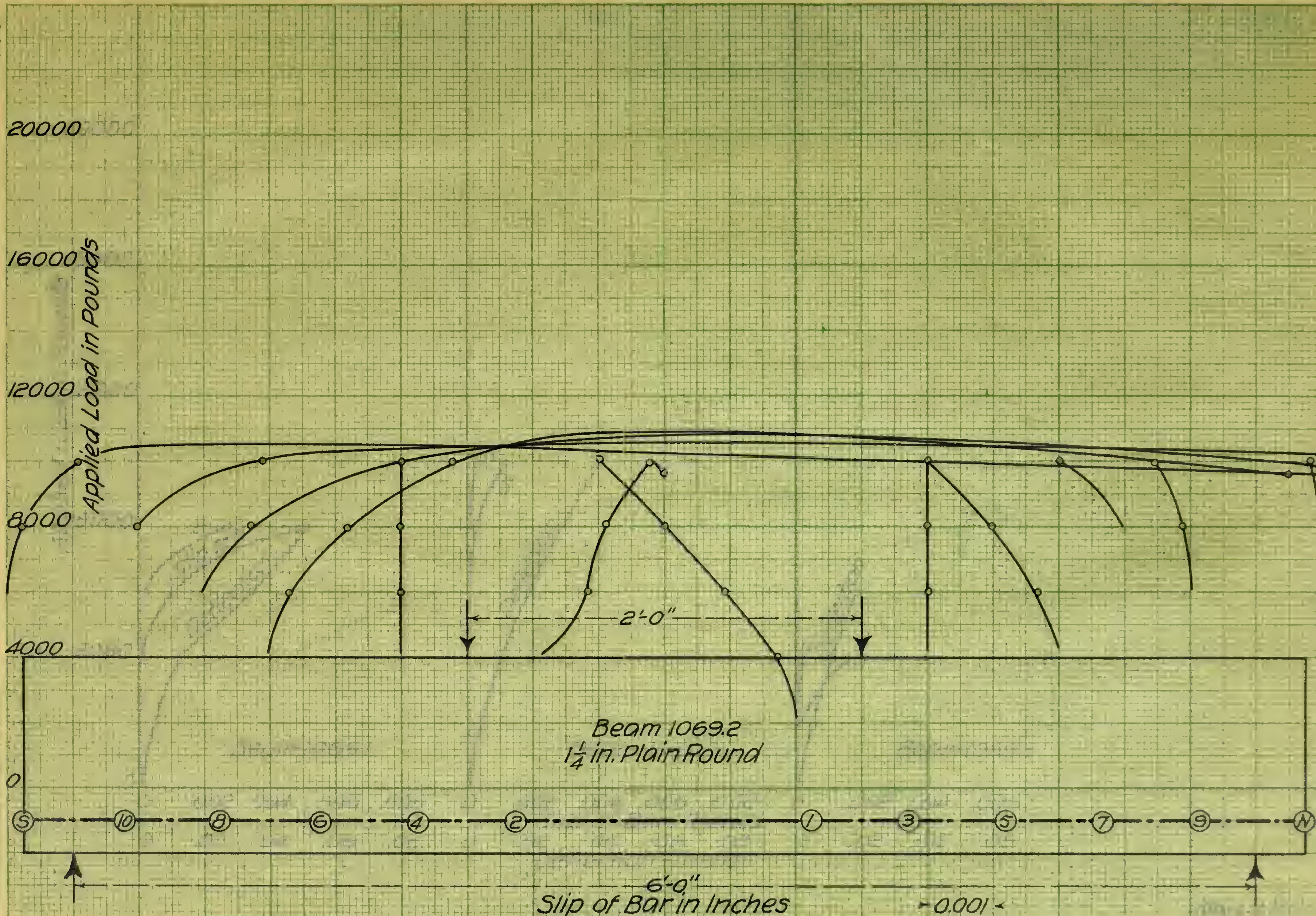

Slip of Bar in Inches
Applied Load in pounds
1½ in. corrugated Round
5'-0"
4000
8000
12000
16000
20000



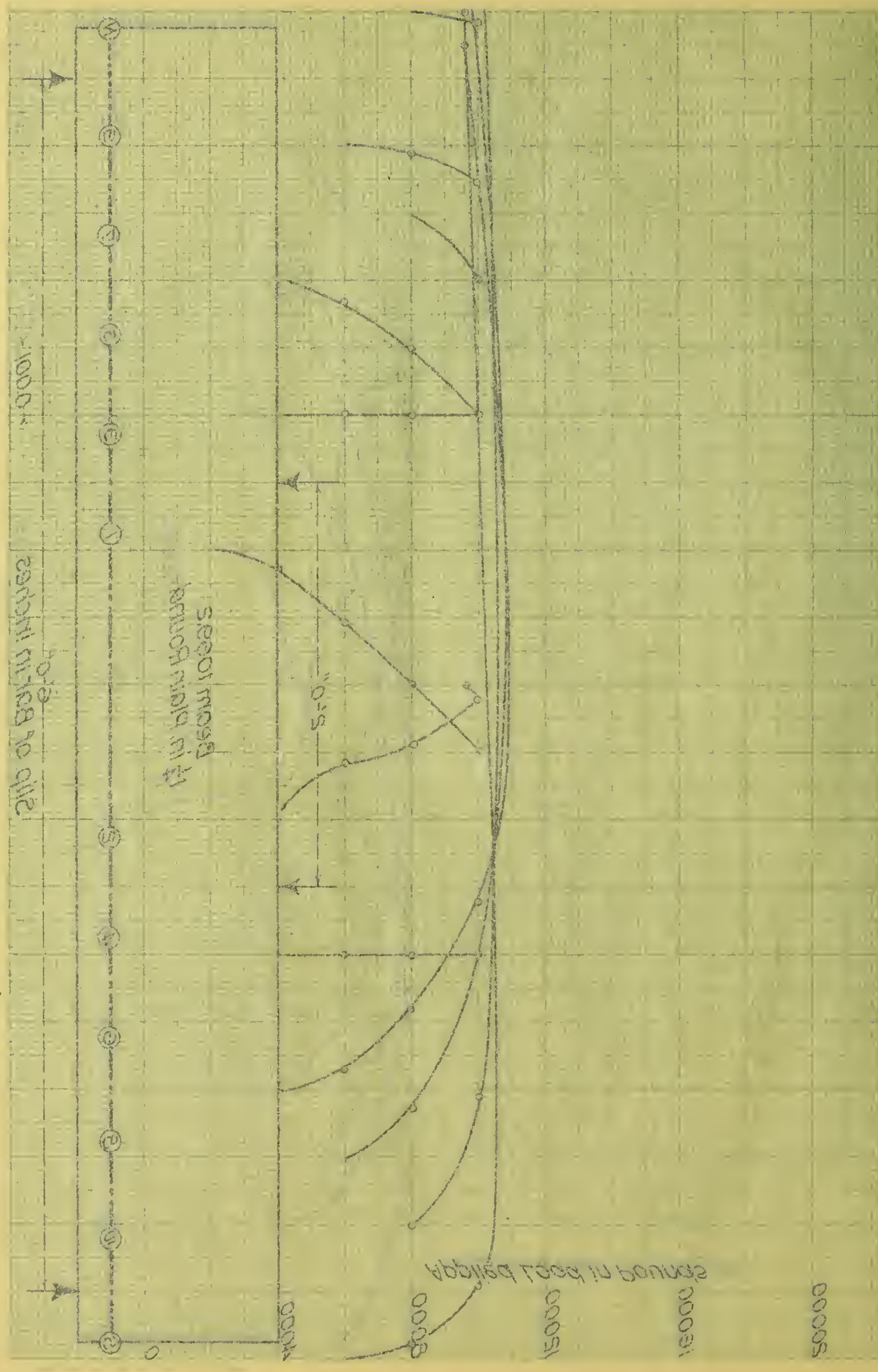
20000
16000
12000
8000
4000
0
Applied Load in Pounds
2'-0"
Beam 1069.1
1 1/4 in. Corrugated Round
S
10
8
6
4
2
C
1
3
5
7
9
N
6'-0"
Slip of Bar in Inches
0.001"
Albright R.H.

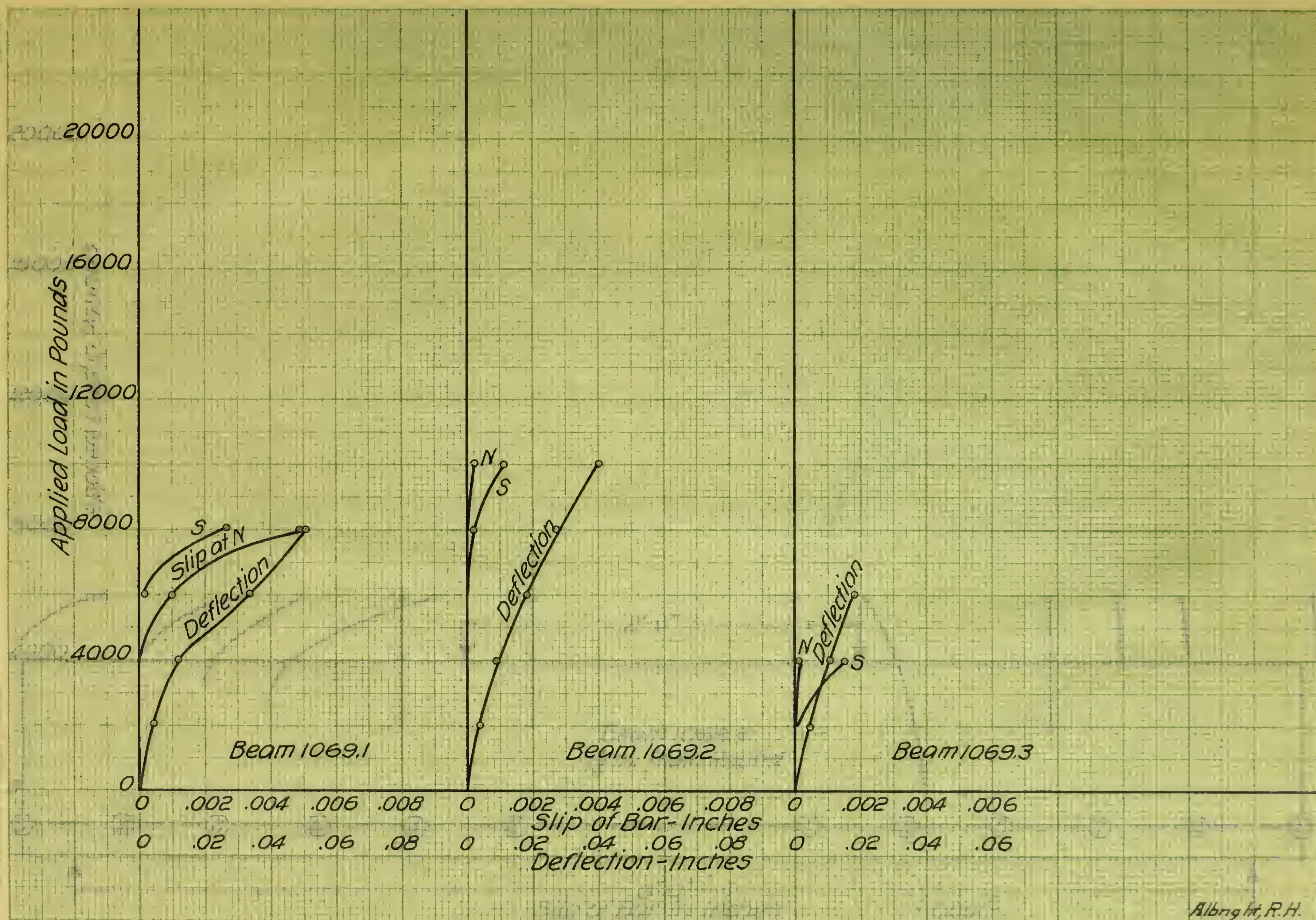


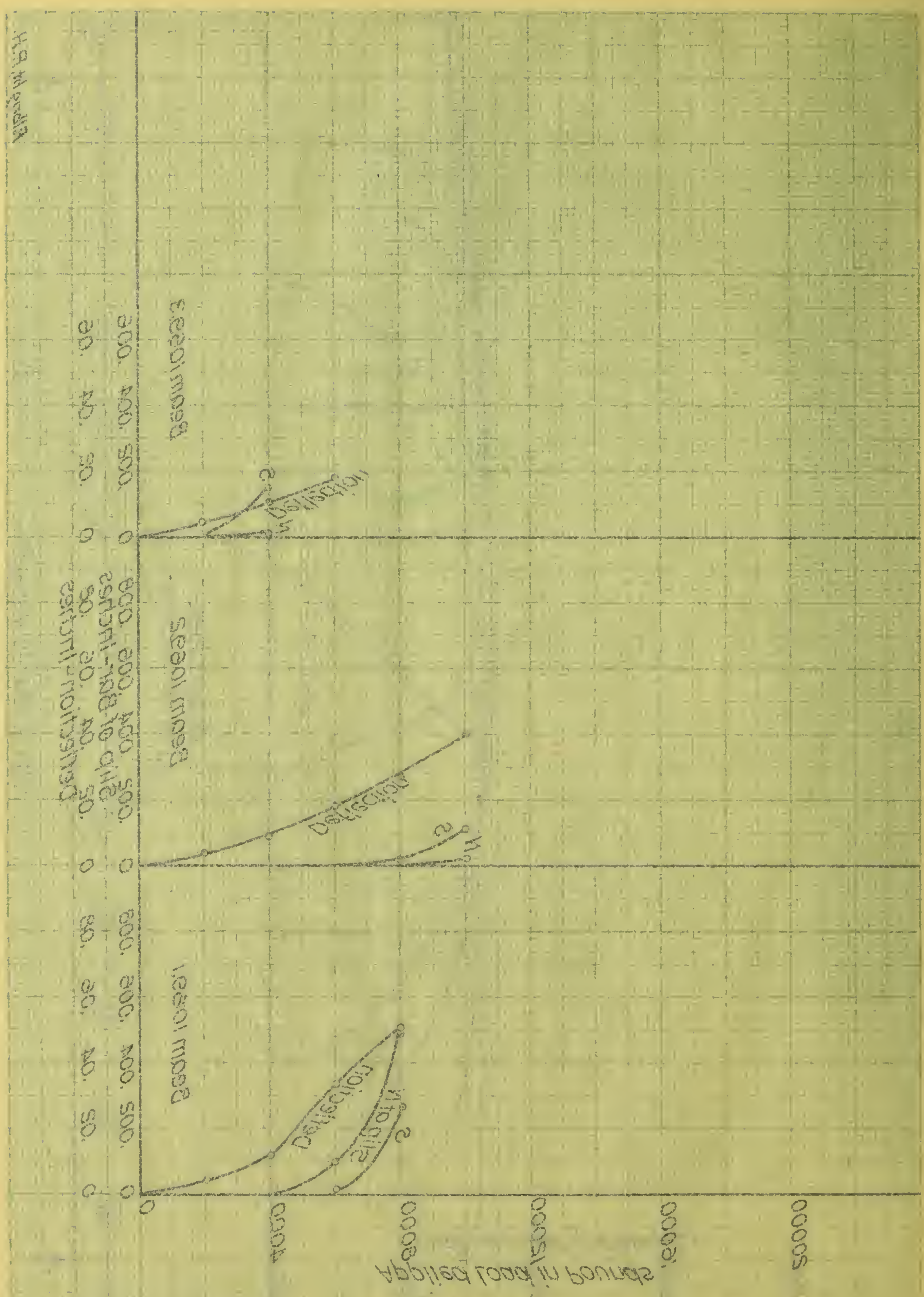
Slip of Bar in inches
6'-0"
1/1000"
1½ in Corrugated Round
Applied Load in Pounds
4000
8000
12000
16000
20000



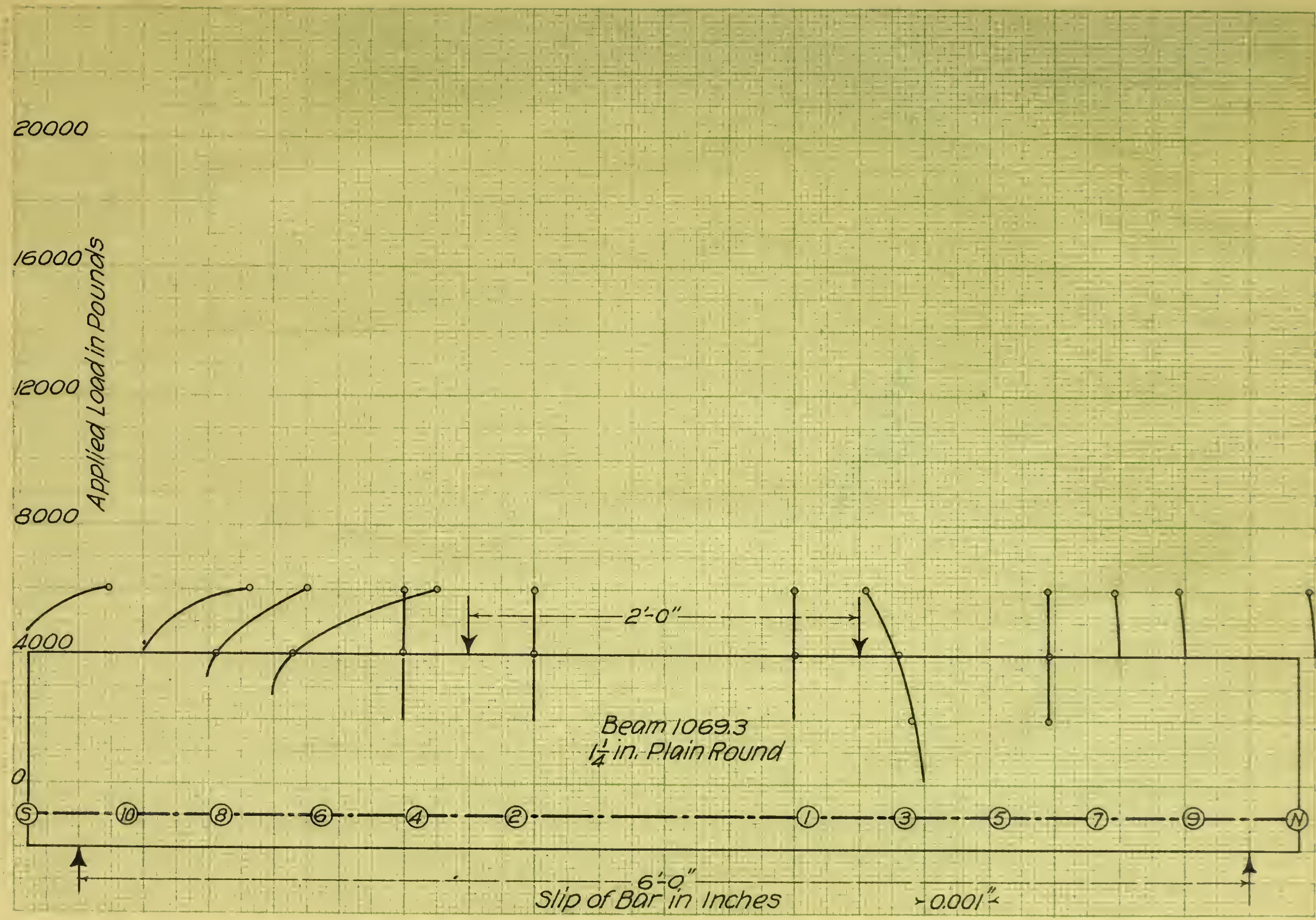
20000
16000
12000
8000
4000
0
Applied Load in Pounds
2'-0"
Beam 1069.2
$1\frac{1}{4}$ in. Plain Round
S
10
8
6
4
2
1
3
5
7
9
N
6'-0"
Slip of Bar in Inches
0.001


Slip of Bar in inches
Applied Load in pounds
5'-0"
4000
8000
12000
16000
20000


Applied Load in Pounds
20000
16000
12000
8000
4000
0
S
Slip at N
Deflection
Beam 1069.1
N
S
Deflection
Beam 1069.2
N
Deflection
S
Beam 1069.3
0 .002 .004 .006 .008
0 .002 .004 .006 .008
0 .002 .004 .006
Slip of Bar - Inches
0 .02 .04 .06 .08
0 .02 .04 .06 .08
0 .02 .04 .06
Deflection - Inches
Albright, R.H.



Applied Load in Pounds
Deflection
Strains



20000
16000
12000
8000
4000
0
Applied Load in Pounds
2'-0"
Beam 1069.3
1¼ in. Plain Round
S
10
8
6
4
2
1
3
5
7
9
N
6'-0"
Slip of Bar in Inches
0.001"